

ESSAYS ON SOCIALLY AND ENVIRONMENTALLY RESPONSIBLE OPERATIONS

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For the goals to be reached, everyone needs to do their part:
governments, the private sector, civil society and people like you.

– *UN Sustainable Development Goals, September 25, 2015*

*Dedicated to Nalini and Harish,
for without their unconditional love, support, and inspiration
none of this would have happened.*

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SUMMARY

The three essays in this dissertation focus on social and environmental dimensions of managing the operations of organizations. Specifically, this dissertation: (i) employs analytical (e.g., econometric, game-theoretic and optimization models) and empirical (e.g., event study) techniques; and (ii) encompasses the following three areas: healthcare operations, sustainability, and nonprofit operations.

Healthcare Operations. While the majority of the healthcare operations management literature focuses on the demand side of the organ transplantation, I focus on the supply-side to understand the socioeconomic costs of suboptimal quantity and/or quality of organs recovered for transplantation. I develop an analytical model to study the effects of operational decisions of the two key supply-side entities, namely, the organ procurement organization (OPO) and hospital, on their respective payoffs and on societal outcomes, i.e., quality-adjusted-life-year increments. Through my analysis, I identify current misalignments in the objectives of the OPO, the hospital, and the social planner. Further, I recommend an administratively feasible and Pareto-improving contract that the social planner can use to achieve socially-optimal performance.

Sustainability. Over the last two decades, firms have been appointing corporate sustainability executives (CSEs) to be part of their top management teams (TMTs). A CSE is the primary executive in the TMT with responsibility over the firm's corporate sustainability strategy. I add to the understanding of the empirical link between CSE appointments and financial performance by using a stock price-based performance measure. My findings suggest that although, on average, the shareholder value effect of CSE appointments is not significantly different from zero, the stock market reacts more positively under certain firm- and industry-specific conditions.

Nonprofit Operations. Non-profit organizations (NPOs) that support and serve distressed individuals are often the last resort for those who are marginalized in society. To

reduce mismatches between client needs and services provided, NPOs can invest in advisory effort during the intake process. While indirectly beneficial for generating social impact, advisory efforts consume resources that NPOs could have spent in delivering impact-generating services. I develop an analytical model to study how an NPO should invest its limited resources between the advisory and service delivery activities. The analysis sheds light on when to invest more in an activity, and when to specialize on a single service type.

CHAPTER 1

INTRODUCTION

On September 25, 2015, countries across the globe adopted a set of 17 goals, collectively termed as UN Sustainable Development Goals, ranging from social responsibility (such as no poverty and good health) to environmental responsibility (such as clear water and energy). One of the key reasons was to garner commitment from all parties including governments, the private sector, civil society and individuals to ensure the fulfillment of these goals.

Over the last two decades, the increasing importance of social and environmental responsibility among practitioners is receiving considerable attention in academic research. There exists a vast literature in management science that studies reasons why organizations engage in socially and environmentally responsible practices and activities, and their impact on various measures of performance (e.g., profitability, operational performance, greenhouse gas emissions, etc.). Although there is an extensive body of analytical and empirical literature on design, development, and implementation of environmentally-responsible operations, there is scope to extend and add to this literature stream by answering new and timely research questions. Further, nonprofit organizations (NPOs) play an important role in alleviating economic and social burdens on the society. There are over 5,000 NPOs in the United States that provide services related to mental health and crisis intervention, civil rights and advocacy, and employment search and training. Scholars in the fields of economics, public policy, and behavioral sciences have extensively studied challenges faced by NPOs such as fundraising, charitable giving, missions and motivations, and governance. In recent years, there is an emerging stream of literature in operations management (OM) that recognizes the unique challenges associated with non-profit operations within supply chains because of the distinct sets of objectives targeted by the for-profit versus the not-for-profit organizations. OM scholars have begun to recognize distinctive challenges of managing operations

of NPOs that deliver social benefits in the presence of limited and uncertain availability of funds. Motivated by these contexts, the three essays in this dissertation focus on social and environmental dimensions of managing the operations of organizations.

The first essay, titled “Improving Societal Outcomes in the Organ Donation Value Chain” (Chapter 2), focuses on improving societal outcomes by focusing on operational actions of the two entities/players (an NPO and a hospital) that comprise the supply-side of the organ donation value chain (ODVC). While the healthcare operations management literature has largely addressed the issue of optimal allocation of organs to waiting patients once an organ becomes available for transplantation, I address the significant supply-side gap between the numbers of eligible potential donors and eventual donors. The significant socioeconomic costs arising from the suboptimal quantity and/or quality of recovered organs form the context of this study, which takes the perspective of the social planner that has an overall quality-adjusted-life-year improvement objective. The analysis identifies current misalignments in the objectives of the two supply-side players and the social planner, that lead to socially suboptimal fractions of organs recovered from different types of potential donors. Further, I recommend an administratively feasible and Pareto-improving contract that the social planner can use to help the ODVC achieve socially-optimal performance.

The second essay, titled “When do Appointments of Corporate Sustainability Executives Affect Shareholder Value?” (Chapter 3), investigates the shareholder value effects of appointing corporate sustainability executives (CSEs) to firms’ top management teams (TMTs). Although there is a vast literature on sustainable practices and strategies and their relationships with various measures of firm performance, little is known about the nature of the empirical link between CSE appointments and financial performance. I add to the understanding of this link between CSE appointments and financial performance by using a stock price based performance measure. I also investigate how the stock market reaction depends on the following firm- and industry-specific factors: (i) whether the responsibilities specified for the CSE appointee are focused versus broad; (ii) appointments announced sub-

sequent to an adverse sustainability-related event; (iii) sustainability-related performance of the announcing firm; and (iv) the level of regulatory sanctions experienced by the industry in which the announcing firm operates. I find that although the stock market reaction to CSE appointments is overall value neutral, the stock market reacts more positively under certain firm- and industry-specific conditions. These findings demonstrate nuances in the market reactions to CSE appointments depending on various firm-specific factors, thereby helping executives and stakeholders better understand the shareholder value effects of appointing CSEs to TMTs.

The third essay, titled “Balancing Advisory and Service Delivery Efforts in Nonprofits: A Service Design Perspective” (Chapter 4), focuses on a service design dilemma for resource-constrained NPOs that need to balance advisory and service delivery efforts to maximize their social impact. This study is motivated by several NPOs, such as Daya and Georgia Works, that support and serve distressed individuals and face a complex task because their clients are often unable to articulate their needs. I model the NPO’s service-design problem that captures this essential trade-off: while increasing advisory efforts increases the likelihood of clients receiving the appropriate services (reduces mismatches), it limits the resources available for different service delivery efforts. I derive optimal advisory and service delivery efforts as a function of the state of the NPO (resources and services) and clients’ characteristics (mix and diversity of needs). To the best of my knowledge, this is one of the first few studies that focus on designing the services of NPOs that not only deliver services to the clients, but also need to help the clients obtain a better understanding of their needs. Overall, in the context of service-design for NPOs, this study sheds light on how to allocate scarce resources between inter-dependent activities, when to invest more in an activity, and when to specialize on a single service type.

CHAPTER 2

IMPROVING SOCIETAL OUTCOMES IN THE ORGAN DONATION VALUE CHAIN

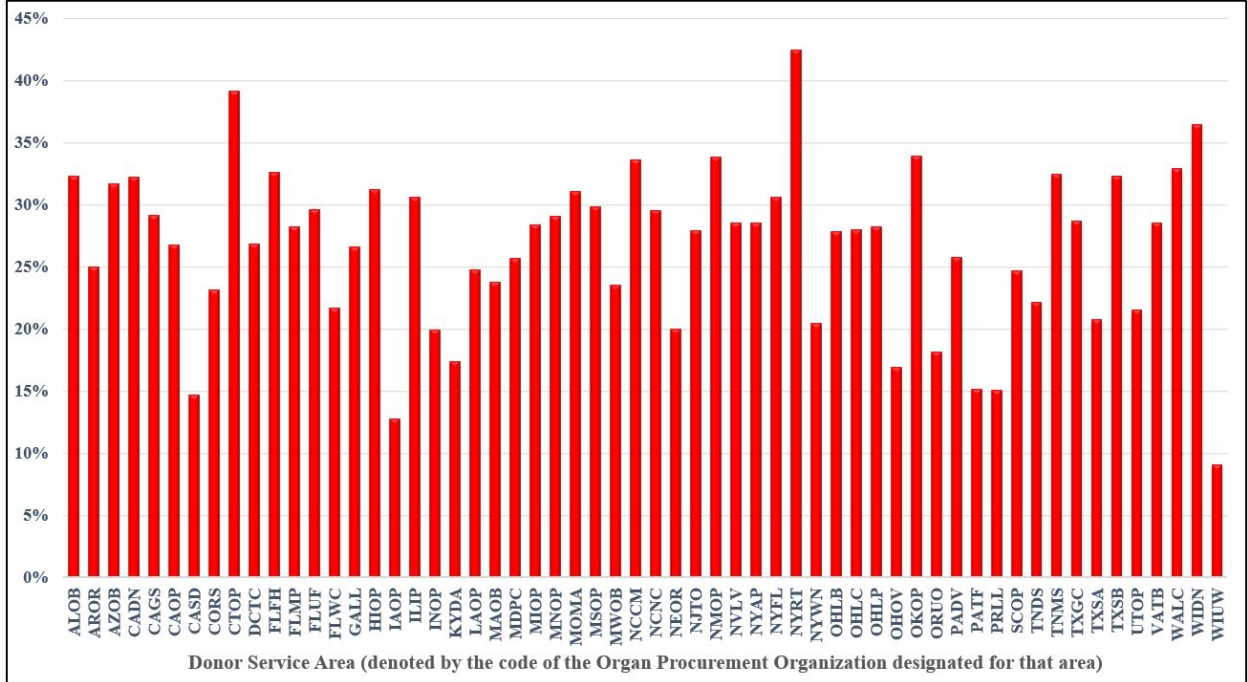
2.1 Introduction

The mismatch between demand and supply of organs for transplantation is significant: as of December 2016, approximately 120,000 individuals in the US were registered on the waitlist to receive an organ. This number is substantially large compared to supply-side figures: in the year 2016, there were 15,948 donors who accounted for 33,611 transplants (HRSA 2016). Despite the creation of donor registries, the use of organs from expanded-criteria donors, and improvements in surgical techniques, organ preservation, and immunosuppressant drugs, there is still a significant gap between demand and supply of organs, which results in significant socioeconomic costs. For instance, according to the US Renal Data System’s report (USRDS 2013), the cost to an end-stage renal disease patient for dialysis is \$89,000/year as compared to approximately \$32,000 for renal transplant surgery and \$25,000/year for post-surgery care. The US Medicare’s budget absorbs about 80% of dialysis costs and about 53% of renal transplantation surgery and post-surgery care costs.

In the context of the mismatch between demand and supply of organs, a statistic worth noting is that across the donor service areas¹ (DSAs) in the US, the average (median) percentage of eligible² potential donors from whom *no organs are recovered* is 26.6% (28%). Figure 2.1 highlights the significant gaps in the numbers of donors from whom at least one organ is recovered and the numbers of eligible deaths (i.e., deceased individuals who meet

¹ The Centers for Medicare & Medicaid Services has divided the US into 11 regions, which are further divided into 58 donor service areas for planning and managing organ recovery and allocation efforts.

² According to Federal regulations, an eligible potential donor is an individual 75 years or younger whose death meets American Academy of Neurology Practice’s (AANP’s) neurological criteria for determining brain death, and who does not exhibit one or more active infections that are contraindications for organ donation such as tuberculosis, rabies, meningitis, malaria, etc. (OPTN 2017; p. 4–5).



Note: This figure shows, for each of the 58 DSAs in the US, the number of eligible potential donors from whom no organ is recovered as a percentage of the number of eligible deaths at hospitals in the DSA. The plots are based on data for the year 2016 published by the US Scientific Registry of Transplant Recipients (SRTR 2016). The first two letters in the horizontal axis marker indicate the State to which the DSA belongs.

Figure 2.1: Eligible potential donors from whom no organ is recovered as a percentage of the number of eligible deaths at hospitals, by donor service area

the criteria for organ donation), across the 58 DSAs in the US.

While the healthcare operations management literature has largely addressed the issue of optimal allocation of organs to waiting patients once an organ becomes available for transplantation (Alagoz et al. 2004; 2007, Ata et al. 2016, Kreke et al. 2002, Su and Zenios 2006, Zenios et al. 2000, Zenios 2002), our work addresses the significant *supply-side* gap between the numbers of eligible potential donors and eventual donors. We model the operational decisions of the two key supply-side entities in a cadaver organ donation value chain (ODVC) within a DSA – namely, the organ procurement organization (OPO) and hospital (typically the main trauma center within the DSA) – that determine organ recovery outcomes. The OPO is a non-profit entity designated by the Centers for Medicare & Medicaid Services (CMS) to carry out the following main tasks in an ODVC: collaborate with hospitals in

its DSA, educate hospital staff on standard procedures for organ donation, review medical records of identified potential organ donors, request family authorization for organ donation, and coordinate recovery, matching, and transportation of recovered organs. From the standpoint of the hospital, one of the key provisions of the revised Medicare conditions for organ donation (Federal Ruling 42 CFR 482 on June 22, 1998), also termed as the “donation rule,” is that the hospital is required to contact its affiliated OPO in a timely manner about individuals whose death is imminent or who have died while in the hospital’s care. Traino et al. (2012) underscore the importance of coordinating the operational actions of these two supply-side entities. Their study emphasizes the need for strong OPO–hospital relationships in the form of effective channels of communication and frequent contact in order to ensure timely identification and referral of potential donors by hospitals to OPOs.

However, several studies lament the lack of coordination between hospitals and OPOs as one of the main reasons for suboptimal levels of organ recovery from eligible deceased donors (Brown 2000, Graham et al. 2009). Shafer et al. (2003; 2004) point out that OPOs are resource-constrained organizations with limited budgets and have to be selective in the number and type of staff on their payroll, which has implications for organ recovery outcomes. For example, Shafer et al. (2004) show that although it requires a considerable investment of OPO resources, having a full-time OPO staff member present at the donor hospital can significantly improve organ recovery outcomes.

Further, studies also show that suboptimal organ recovery outcomes result from hospitals’ priority to providing care to living patients as compared to deceased donors, health care professionals’ (HCPs’) lack of knowledge regarding the concept of brain death (BD), and delays by hospital staff in referring potential donors to the OPO (Opdam and Silvester 2004, Sheehy et al. 2003, Walters 2009). Doyle et al. (2014) and Walker (1998) highlight that deceased donors often receive lower priority for care than other patients in the hospital, resulting in delays in access to the operating room (OR) for surgical recovery of organs. Jendrisak et al. (2002, p. 1), Jensen (2011, p. 165–166), Moazami et al. (2007), and

Zaroff et al. (2002) point out that, of the logistical issues involved in the organ recovery process, timely access to the hospital’s OR for surgical recovery of organs can be one of the most problematic. From a socioeconomic standpoint, delays in the organ recovery process negatively influence the quality of the recovered organ and, hence, graft survival and quality of life of the recipient post-transplantation (Cantin et al. 2003, Schnitzler et al. 2003).

The significant socioeconomic costs arising from the suboptimal quantity and/or quality of recovered organs form the context of our study, which focuses on the following operational actions for organ recovery by the OPO and the hospital: the OPO’s effort level in seeking authorization for organ donation, the hospital’s effort level in identifying and referring potential donors, and the hospital’s priority scheme for scheduling organ recovery and other surgeries in its OR. In our analysis, we take the perspective of the social planner (Department of Health and Human Services,³ DHHS), that uses quality-adjusted life years (QALYs) as a measure of health outcomes. Introduced by Klarman and Rosenthal (1968), QALY was developed as a way to combine length and quality of life into a single measure. The US Panel on Cost-Effectiveness in Health and Medicine recommends that QALY be used as the principal measure of health outcomes (Siegel et al. 1996). This measure has also been used in the operations management literature that focuses on the demand side of the ODVC to examine trade-offs involved in organ allocation policies (e.g., Ahn and Hornberger 1996, Bertsimas et al. 2013, Dai et al. 2017, Zenios et al. 2000, Zenios 2002).

We aim to answer the following research questions: (i) How do the operational actions of the supply-side ODVC players impact their individual payoffs and societal outcomes? (ii) What mechanisms can be implemented by the social planner to improve societal outcomes in the ODVC as well as ensure that no player is worse-off? The main contributions of our work are two-fold. *First*, we develop a model that enables us to study the effects of the operational decisions of the supply-side players (OPO and hospital) in an ODVC, on their respective payoffs and on societal outcomes. The model reflects key contextual components,

³ The Department of Health and Human Services is a federal agency tasked with protecting the health of all US nationals and providing essential human services.

including donor heterogeneity, organ recovery reimbursement rates for the hospital, cost to the hospital from the wait times experienced by its other patients, shared OR capacity between organ recovery and other procedures, and increments in QALYs for organ recipients and the hospital’s other patients. Our analysis identifies current misalignments in the objectives of the OPO, the hospital, and the social planner, that lead to socially suboptimal fractions of organs recovered from different types of potential donors. *Second*, we recommend an administratively feasible and Pareto-improving contract that the social planner can use to help the ODVC achieve socially-optimal performance.

2.2 Literature Review

Our work draws on and contributes to three literature streams: *(i)* The operations management (OM) and healthcare economics literatures that address the demand and supply of organs for transplantation; *(ii)* The medical literature on organ donation and recovery that presents the findings and perspectives of medical researchers and healthcare professionals; and *(iii)* The literature on non-profit operations management and humanitarian supply chains that considers the distinctive features of non-profit operations.

The majority of the related OM literature focuses on the *demand* side of an ODVC. The demand for organs is known in the form of the national waitlist maintained by the United Network for Organ Sharing (UNOS). Several research studies have addressed the issue of optimal allocation of organs to waiting patients once an organ becomes available for transplantation. These studies have recommended various organ allocation policies to maximize social or individual welfare, with organ supply assumed to be exogenous (Alagoz et al. 2004; 2007, Su and Zenios 2006, Zenios et al. 2000). Ata et al. (2016), Ata et al. (2017), Kreke et al. (2002), and Zenios et al. (2000) use simulation models and the UNOS database of previous organ transplantations to study the potential effects of changes to existing organ allocation policies. Recent studies in healthcare economics have examined ways to improve the *supply* of organs for transplantation, e.g., donations by *living* donors. For instance,

Ashlagi and Roth (2012) and Roth et al. (2007) show that two-way and three-way kidney exchanges involving patients for whom a living donor is willing to donate an organ but is incompatible (e.g., blood- or tissue-type incompatibility between the patient and the living donor) could lead to a substantial increase in the number of transplants.

To our knowledge, the paper by Arikan et al. (2017) is the only other paper in the OM literature that discusses the supply side of organ transplantation from cadaveric donors. They perform an empirical study to understand drivers of geographical differences in organ procurement rates and propose that low-quality organs should immediately be made available more widely rather than sticking to geographical constraints that currently apply to all organ quality types. Our work complements this paper by studying the operational actions of the supply-side players (OPO and hospital) in a cadaver ODVC.

We also draw on the medical literature to consider the findings and views of the medical community on ways to alleviate the wide gap between the demand and supply of organs for transplantation. Traino et al. (2012) implemented a national test of the Rapid Assessment of hospital Procurement barriers in Donation (a tool for identifying barriers to donor identification, donor referral, and requesting families for authorization) and found that the hospital–OPO relationship has inherent tensions. This is because the HCPs caring for potential donors and trying to keep them alive are the same professionals on whom the system relies for referrals. Our work builds on their major recommendation – as also reiterated by other researchers (see Goodman et al. 2003) – that special efforts, such as interventions to improve donor identification and periodic meetings among ODVC members, are needed to ensure that OPOs and hospitals coordinate their efforts to ensure the successful conduct of organ recovery activities.

Ranjan et al. (2006) conducted a retrospective financial analysis of the management of potential donors showed that organ recovery for Medicare-approved transplant hospitals can in fact be financially attractive for those hospitals. OPOs typically reimburse hospitals in a timely manner and at Medicare-prevailing rates, which are typically higher than third-party

insurance rates. Thus, the financially attractive and timely reimbursements are at odds with the observation of low or insufficient priority for organ recovery by hospitals (Jensen 2011; p. 165–166). However, in their analysis, Ranjan et al. (2006) only include the direct costs of maintaining a potential donor and do not take into account indirect costs (e.g., disutility associated with dealing with the subject of organ donation or the effect of organ recovery activities on delays experienced by the hospital’s other patients). Domingos et al. (2012) emphasize that organ recovery outcomes must be considered as a component in the measure of the quality of care provided by hospitals in order to drive improvements in organ recovery outcomes. They propose that not only OPOs but also intensive care units at hospitals should be evaluated on the conversion rate of potential to actual donors (i.e., donors from whom organs are eventually recovered). Through our analytical model, we attempt to explore the possibility of introducing contractual levers in order to better align the objectives of the OPO and the hospital with the societal objective of the social planner.

There is an emerging stream of literature in OM that recognizes the unique challenges associated with non-profit operations within supply chains because of the distinct sets of objectives targeted by the for-profit versus the non-profit organizations (Feng and Shanthikumar 2016, Tomasini and Van Wassenhove 2009). Bhattacharya et al. (2014) and Holguin-Veras et al. (2012) discuss the differences between humanitarian supply chains and traditional supply chains, including supply chain design requirements and coordination mechanisms. Berenguer et al. (2014) highlight the lack of inter-organization collaboration as a recurring challenge in non-profit operations, which is true of our context as well; the divergence between individual and societal objectives in an ODVC leads to unique interrelationships and coordination challenges. Ergun et al. (2014) utilize a cooperative game theoretic model to explore improvements in humanitarian operations through collaboration among the different parties involved, including governmental, private, and non-governmental organizations. Similar to their work, we utilize a game theoretic model to analyze the interrelationships between the operational decisions and the payoffs of the supply-side players in an ODVC.

The preceding review of the related literature underscores the importance of coordinating the operational actions of the supply-side ODVC players in the form of relevant efforts, timely referrals, and timely organ recovery; yet interactions among contextual parameters and the decisions of these players have not been well-studied. We address this important literature gap with our analysis that takes the perspective of the social planner and considers the privately- and socially-optimal operational actions of the OPO and the hospital operating within an ODVC.

2.3 Model (Current Scenario)

The study by Sheehy et al. (2003) shows that larger hospitals (which are typically trauma centers as well) have significantly greater numbers of potential and actual donors – specifically, 19% of hospitals account for 80% of the donations. We therefore focus our analysis on a large hospital in the OPO’s DSA. Based on the organ recovery process and the sequence of multiple interactions between the OPO and the hospital, we develop an analytical model to represent the current scenario for a focal organ and then, through our analysis, propose a contractual mechanism to improve the societal outcome of the ODVC.

Several research studies (e.g., Schold et al. 2005, Swanson et al. 2002) highlight that a combination of factors, such as age and medical history of the potential donor, leads to variation in the quality of organs that can be recovered from potential donors. Ojo (2005) reports that graft survival for “expanded-criteria” or marginal-quality cadaveric donor kidneys is 8% lower at 1-year, and 15-20% lower at 3-5 years post-transplantation compared to non-marginal kidneys (an expanded-criteria-donor for kidneys is any donor above the age of 60 years, or a donor above the age of 50 years with two of the following: history of high blood pressure, creatinine level greater than or equal to 1.5 milligrams per deciliter, or death resulting from a stroke). Therefore, since organ quality determines graft survival as well as the quality of life of the recipient post-transplantation (Cantin et al. 2003, Schnitzler et al. 2003), the quality of the recovered organ is an important consideration for the social planner

(DHHS).

To allow for this heterogeneity, we consider the arrival of two types of medically suitable potential donors who meet the criteria for imminent BD – *type 1*, from whom the focal organ recovered would be of higher quality (known *a priori* based on health history and tests early in the process), and *type 2*, from whom the organ recovered would be of lower quality. We assume that the arrival rates of potential donors of each type are independent. Let λ_{p1} and λ_{p2} denote the (Poisson) arrival rates of type 1 and type 2 potential donors, respectively, such that $\lambda_{p1} + \lambda_{p2} = \lambda_p$.

However, current federal regulations and donor referral and donor management practices do not require the hospital or the OPO to differentiate their operational actions based on donor heterogeneity. For instance, the reporting by the OPO to CMS of numbers of eligible deaths and eventual donors (the data that is presented in Figure 2.1), does not reflect the heterogeneity in the quality of organs that *can be* recovered from potential donors or in the quality of organs that *are* recovered from authorized donors. Further, OPOs provide hospital staff with criteria or “triggers” pertaining to the health condition of the patient which, when met, indicate that the patient may be a potential organ donor and that the OPO should be contacted (see Appendix A for an example of a “trigger card” provided by an OPO to HCPs). Neither the donation rule (discussed in Section 2.1) nor do the descriptions of triggers reflect the heterogeneity in the quality of organs that can be recovered from potential donors. Because OPOs and hospitals currently make their operational decisions without explicitly taking into account the quality of organs that can be recovered, for the model that captures the current scenario, incoming potential donors are regarded as a single pool with overall arrival rate λ_p .

2.3.1 OPO and Hospital Actions

We model the interaction between the OPO and the hospital within an ODVC as a Stackelberg game. The hospital, because of its say in the referral of potential donors to the OPO and

in OR scheduling, is the Stackelberg leader. The hospital makes two operational decisions – the level of effort to commit to organ recovery activities, and the OR priority assigned to organ recovery as compared to other procedures. The OPO’s decision is the level of effort to commit towards interacting with potential donors’ families and seeking authorization for organ donation. We discuss these decisions further in Sections 2.3.2, 2.3.3, and 2.3.4.

2.3.2 Hospital’s Effort Level

The hospital decides its level of effort (ξ_h) to commit to organ recovery activities – specifically, personnel training, time, and effort involved in identifying and referring potential donors. Based on an audit of 5,551 deaths in 12 hospitals, Opdam and Silvester (2004) report that hospitals withdrew medical support for 38% of potential donors who met eligibility criteria for organ donation. Using data on 3,329 potential heart-beating donors across 284 hospitals, Walters (2009) reports that 23% of these donors did not have BD tests carried out. Several studies reveal that HCPs find it difficult to broach and discuss the subject of organ donation with the families of potential donors (Chernenko et al. 2005, Regehr et al. 2004). In particular, Chernenko et al. (2005) estimated that 77% of registered nurses and 44% of doctors found it difficult to communicate and explain the concept of brain death to families. Training-related reasons for HCPs not referring potential donors include lack of knowledge regarding: the concept of brain death; the process of referring potential organ donors to the OPO; and the life-changing outcomes for organ recipients (Molzahn et al. 2003). Also, participating in the process of organ donation is only one aspect of their complex jobs.

We normalize the hospital’s effort level such that $\xi_h \in [0, 1]$ translates into the fraction (f_h) of potential donors who end up as “referred” donors. Missed referral opportunities by the hospital or referrals made after pronouncement of BD are collectively termed as “missed” referrals (Federal Ruling 42 CFR 482 on June 22, 1998).

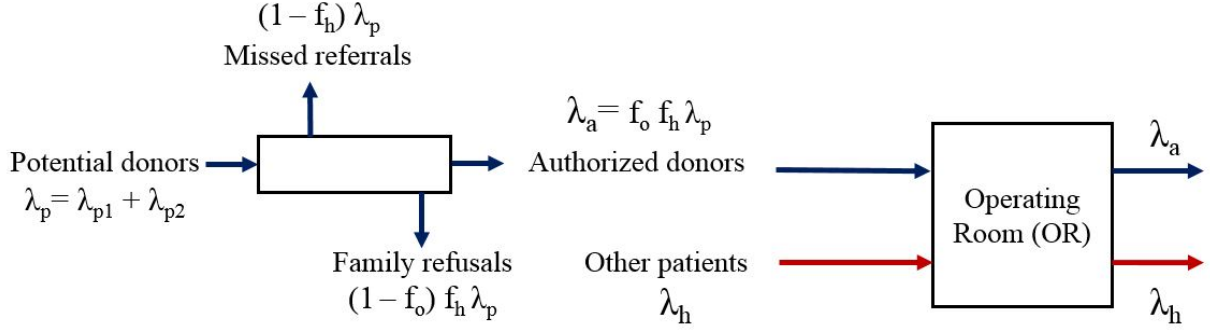


Figure 2.2: Key Components of the Model (Current Scenario)

2.3.3 OPO's Effort Level

Once a potential donor is referred to the OPO, the OPO appoints a family care coordinator to the case, who is responsible for following up with the hospital regarding the health condition of the potential donor and attending to the needs of the potential donor's family members facing the stressful situation.

Siminoff et al. (2009) conducted an event study to show that a training workshop on the use of "effective relational and affective communication techniques," for OPO staff responsible for seeking authorization from the nearest-of-kin for organ donation, led to a significant increase in the likelihood of authorization. The study by Frutos et al. (2002) found that 20.3% of families who initially refused authorization and 65.8% of families who were undecided at first, eventually consented when approached again. Thus, the OPO's effort level $\xi_o \in [0, \theta]$ in the form of interactions with the potential donor's family members, influences the fraction of referred donors who are "authorized" for organ donation after pronouncement of BD. $0 < \theta \leq 1$ captures the resource-constrained environments in which OPOs operate (as discussed in Section 2.1; Shafer et al. 2003; 2004).

We denote the fraction of referred donors who end up as authorized donors by f_o and assume $f_o = \tau \xi_o$, where τ ($0 < \tau \leq 1$) captures donors' or their families' (exogenous) affinities towards organ donation. Thus, the rate of authorized donors from whom organs are recovered is $\lambda_a = f \lambda_p$, where $f = f_h f_o = \tau \xi_h \xi_o$ (see Figure 2.2). As discussed before, in

the current scenario, both the OPO and the hospital regard potential donors as a single pool with overall arrival rate λ_p . Accordingly, in the current scenario, the fractions of referred donors who end up as authorized donors are the same for both donor types. We assume that the flows in Figure 2.2 are such that we can use the Partition Theorem for Poisson Processes (see Cramér and Leadbetter 1967). Also, for simplicity, we assume that the organ recipient is identified from the waitlist immediately after the potential donor becomes an authorized donor, or, that authorized donors can proceed immediately to organ recovery surgery once the hospital’s OR becomes available.

2.3.4 Hospital’s OR Scheduling Policy

The OR is often a hospital’s most constrained resource because of the expensive medical equipment and specially trained staff that are required (Cardoen et al. 2010, Van Houdenhoven et al. 2007). Within the context of ODVCs, Walters (2009) states that a hospital’s resource constraints, including limited OR capacity, may result in suboptimal organ recovery decisions. Jendrisak et al. (2002), Jensen (2011), Moazami et al. (2007), and Zaroff et al. (2002) point out that of the logistical issues involved in the organ recovery process, timely access to the hospital’s OR for surgical recovery of organs can be one of the most problematic. Based on our conversations with ODVC members and reviews of the medical literature, potential reasons for organ recovery surgeries not being accorded requisite OR priority are: (i) Hospitals (implicitly or explicitly) favor living patients over deceased donors in decisions involving allocation or prioritization of use of hospital resources (Doyle et al. 2014, Walker 1998), and (ii) The transplant team members tasked with organ recovery are typically unknown to the hospital’s OR staff as those members come from the transplant hospital, rather than the donor hospital (Regehr et al. 2004).

We model the hospital’s OR as an M/G/1/[2] queueing system. The two classes of patients competing for OR access are: authorized donors (a), and other hospital patients (h) who need OR care, with respective Poisson arrival rates $\lambda_a = f\lambda_p$ and λ_h (see Figure

2.2). Patients in each class require a random amount of time in OR care, with mean $\frac{1}{\mu_x}$ and second moment ν_x , where $x \in \{a, h\}$. Denote $\rho_x = \frac{\lambda_x}{\mu_x}$. Let \mathcal{A} be the set of possible OR scheduling policies. For a chosen policy $\chi \in \mathcal{A}$, let w_a and w_h denote the resulting average wait times in queue for the patients of each class. We assume $\rho_a + \rho_h < 1$, non-preemptive priority (i.e., the patient under consideration is processed completely before the next patient) and first-come first-serve policy within each of the two classes of patients. Based on our interviews with ODVC members, including a hospital trauma care manager, we make the realistic assumption that the mean service time for the organ recovery surgery in the OR is relatively low compared to the mean interarrival time of potential donors to the process.

Assumption A1. *The mean service time for organ recovery surgery in the OR is low compared to the mean interarrival time of potential donors, i.e., $\frac{1}{\mu_a} \ll \frac{1}{\lambda_p}$.*

2.3.5 OPO and Hospital Objectives

The OPO has to meet the volume-based standard (specifically, conversion rate of potential donors to actual donors) set by CMS in order to maintain its Medicare certification. Also, a review of the mission statements of various OPOs, including Carolina Donor Services, Lifelink of Georgia, Living Legacy Foundation of Maryland, Gift of Life Michigan, and Nevada Donor Network, among others, indicates that OPOs aim to maximize the volume of authorized donors in their respective DSAs. Thus, the OPO currently maximizes $\pi_{opo} = \lambda_a = f\lambda_p$, the rate of authorized donors. We denote the OPO's effort level that maximizes π_{opo} as ξ_o^* .

For its services related to caring for authorized donors, the hospital receives a reimbursement from the OPO, irrespective of organ recovery surgery outcomes (e.g., if the organ is deemed to be unviable by the recipient's transplant surgeon during organ recovery surgery; CMS Ruling CMS-1543-R, p. 6–8). This reimbursement consists of two components: a fixed reimbursement rate per authorized donor (R_{af}) that includes charges for laboratory tests, medical equipment use, and anesthesiology consultation, among others, and a variable reim-

bursement rate per authorized donor per unit care time (R_{av}), which depends on the wait time (w_a) of the authorized donors in the intensive care unit before organ recovery surgery in the OR. The emotional stresses and discomfort for the hospital staff involved in organ recovery efforts (Chernenko et al. 2005, Regehr et al. 2004) results in a non-linear cost C_e to the hospital; we assume $C_e = \frac{c_e}{2} \xi_h^2$.

We denote the average per-patient reimbursement rate associated with the hospital's other patients by R_h . Let C_h denote the net cost to the hospital in the form of customer dissatisfaction and reputation loss arising from the wait times experienced by the hospital's other patients (Guinet and Chaabane 2003, Hall 2006). For exposition, we assume that $C_h > 0$ subsumes the variable reimbursement rate (per patient per unit time) applicable to the care time of the hospital's other patients. As in Green et al. (2006) and Guinet and Chaabane (2003), we assume C_h to be linear in the wait time w_h , i.e., $C_h = c_h w_h$. Thus, the hospital's payoff rate is:

$$\pi_h = f\lambda_p R_{af} + f\lambda_p R_{av} w_a + \lambda_h R_h - c_h w_h - \frac{c_e}{2} \xi_h^2. \quad (2.1)$$

Friedman and Pauly (1983) find that even not-for-profit hospitals exhibit a profit-maximizing response to reimbursement terms. Within the context of ODVCs, Rios-Diaz et al. (2017) find that the hospital's ownership-type (for-profit versus not-for-profit) is not associated with significantly different conversion rates of potential donors to actual donors. Furthermore, studies also find that for-profit and not-for-profit hospitals behave in a similar manner when responding to policy changes (Deneffe and Masson 2002, Duggan 2000). Therefore, in the ODVC context, the hospital's payoff function is likely to be structurally similar if it were not for-profit. However, in Section 2.6, we reflect on the implications for our results if the hospital's objective function had a volume-of-care component.

2.3.6 Social Planner’s Objective

We represent the social planner’s objective in terms of the quality-adjusted life years (QALYs) added to patients post-care. Introduced by Klarman and Rosenthal (1968), QALY was developed as a way to combine length and quality of life into a single measure. QALY calculations are based on the idea that individuals transition through health states over time and that each health state has a utility attached to it (in terms of life-years weighted by their qualities). The utility of a health state is measured on a cardinal scale of 0–1, where 0 indicates death and 1 indicates full health. Standardized survey instruments (such as the “EQ-5D” survey) are used to estimate transition probabilities for the population. Responses to the surveys are elicited either from samples of the general population or from groups of patients. Finally, to obtain the QALYs added, the discounted utilities of health states over time are summed (for a more detailed explanation, see Weinstein et al. 2009). The US Panel on Cost-Effectiveness in Health and Medicine recommends that QALY be used as the principal measure of health outcomes (Siegel et al. 1996).

From a socioeconomic standpoint, delays in the organ recovery process negatively influence the quality of the recovered organ and, hence, graft survival and quality of life of the recipient post-transplantation (Cantin et al. 2003, Schnitzler et al. 2003). Jendrisak et al. (2005) tested the outcomes of a novel program whereby authorized donors were transported from the donor hospital to an independent facility housing a dedicated OR for organ recovery surgery. The results of their study demonstrated the benefits of timely OR access for organ recovery surgery, including improved viability of recovered organs. Prolonged waiting for the OR after declaration of BD can lead to an increased likelihood of rejection of the transplanted organ by the recipient’s body or failure of the organ post-transplantation (Blasco et al. 2007, Kunzendorf et al. 2002, Van Der Hoeven et al. 2003).

In addition to delays in the organ recovery process, the variation in organ quality stemming from donor heterogeneity too has a bearing on graft survival as well as quality of life of the recipient post-transplantation. For instance, Ojo (2005) reports that graft survival

for expanded-criteria or marginal-quality cadaveric donor kidneys is 8% lower at 1-year, and 15-20% lower at 3-5 years post-transplantation compared to non-marginal kidneys (an expanded-criteria-donor for kidneys is any donor above the age of 60 years, or a donor above the age of 50 years with two of the following: history of high blood pressure, creatinine level greater than or equal to 1.5 milligrams per deciliter, or death resulting from a stroke). Thus, unlike the current objectives of the OPO and the hospital, the social planner's payoff does depend on the respective fractions of the different types of potential donors who end up as authorized donors. Let f_i denote the fraction of type $i \in \{1, 2\}$ potential donors who end up as authorized donors, and w_{ai} denote the average wait time experienced by type $i \in \{1, 2\}$ authorized donors while waiting for the OR to become available.

We assume the QALYs added for a recipient of the focal organ recovered from a type i potential donor to be of the form $Q_{ai}(1 - q_a w_{ai})$, whereby the value is a decreasing function of the delay (w_{ai}) experienced by the donor in the OR queue (i.e., post-BD), with an upper limit on the delay ($\frac{1}{q_a}$) beyond which there is no QALY addition (Blasco et al. 2007). The parameter q_a captures the sensitivity of the QALYs added to the delay experienced by the donor while waiting for the OR to become available.

Further, empirical studies find that delays experienced by the hospital's other patients while waiting for the OR to become available, lead to increases in postoperative complications and mortality rates (Moran et al. 2005, Shiga et al. 2008). Therefore, we similarly assume the QALYs added for the hospital's other patients who access the OR to be of the form $Q_h(1 - q_h w_h)$, where w_h is the average delay experienced by these patients in the OR queue, and q_h is the sensitivity of QALYs added for the hospital's other patients to the delay experienced by them. Thus, the social planner's payoff rate is:

$$\pi_S = \lambda_h Q_h(1 - q_h w_h) + f_1 \lambda_{p1} Q_{a1}(1 - q_a w_{a1}) + f_2 \lambda_{p2} Q_{a2}(1 - q_a w_{a2}) \quad (2.2)$$

Note that $Q_{a1} > Q_{a2}$; for example, transplants of expanded-criteria or marginal-quality

kidneys add about 15% fewer QALYs in contrast to non-expanded-criteria kidneys (Ojo 2005).

2.4 Analysis

We first present the equilibrium operational decisions of the OPO and the hospital in the current scenario and discuss their divergence from socially-optimal decisions. We then supplement the analytical results with a numerical illustration that is grounded in practice. Thereafter, in Section 2.5, we discuss the design of contracts that yield socially-optimal outcomes. We restrict our analysis to parameter settings where all constraints on the model's variables and decisions are met.

2.4.1 Current (Uncoordinated) Scenario: OPO and Hospital Equilibrium Decisions

OPO: Recall that the OPO is the Stackelberg follower, with the objective of maximizing the volume of care. It is therefore intuitive that the OPO will exert its highest effort level in order to maximize the rate of authorized donors. Hence, $\xi_o^* = \theta$.

Hospital: As discussed earlier, the hospital's chosen OR scheduling policy $\chi \in \mathcal{A}$ will impact its payoff through the resulting average wait times in the OR queue for authorized donors and the hospital's other patients. We transform the control problem of the hospital's choice of OR scheduling policy into an optimization problem of choosing the vector of resulting average wait times $\{w_a, w_h\}$ in the corresponding achievable region for work-conserving scheduling policies. In order to obtain w_a and w_h , we use the results from Gelenbe and Mitrani (1980) that characterize the average wait times in queue achievable in a multiclass queueing system.

$$w_x \geq \frac{\lambda_a \nu_a + \lambda_h \nu_h}{2(1 - \rho_x)}, \quad x \in \{a, h\} \quad (2.3)$$

$$\rho_a w_a + \rho_h w_h = (\rho_a + \rho_h) \frac{\lambda_a \nu_a + \lambda_h \nu_h}{2(1 - \rho_a - \rho_h)} \quad (2.4)$$

We denote the work-conserving scheduling policy that gives absolute priority to authorized donors by I and the policy that gives absolute priority to the hospital's other patients by II . The constraint given by (2.3) is held at equality when $x = a$ for $\chi = I$, and when $x = h$ for $\chi = II$. Under Assumption A1, for both $\chi = I$ and $\chi = II$, w_a and w_h are linear increasing in the fraction (f) of potential donors who end up as authorized donors. Because f increases in ξ_h and in ξ_o , a consequence of increased effort by either the hospital or the OPO is greater OR congestion, leading to longer wait times for both authorized donors as well as the hospital's other patients.

In maximizing the hospital's payoff under the constraints given by (2.3) and (2.4), we obtain that it is optimal for the hospital to always prioritize other patients for service over authorized donors, i.e., $\chi_h^* = II$. This is because a higher priority for authorized donors results in: (i) Longer wait times for the hospital's other patients, resulting in a higher net cost to the hospital C_h , (ii) Shorter wait times for authorized donors, leading to a lower revenue from the variable component R_{av} in the hospital's payoff in Equation (2.1). In terms of practice, the report by Cantin et al. (2003) reflects that hospitals typically delay organ recovery surgeries until other procedures have been completed. Furthermore, our interviews with OPO officials consistently revealed that organ recovery is currently not accorded sufficient priority by hospitals in OR scheduling. Proposition 1 characterizes the hospital's equilibrium effort level ξ_h^* in the current scenario (all proofs are included in Appendix B).

Proposition 1. $\exists \bar{c}_e > 0, \bar{c}_h > 0$, and $\bar{c}_h(c_e) > \bar{c}_h > 0$, such that the following four cases characterize the hospital's equilibrium effort level ξ_h^* :

(i) $c_e > \bar{c}_e, c_h \geq \bar{c}_h$: π_h is decreasing in ξ_h , i.e., $\xi_h^* = 0$;

(ii) $c_e > \bar{c}_e, c_h < \bar{c}_h$: π_h is concave in ξ_h and either:

(a) unimodal, or (b) increasing; i.e., $0 < \xi_h^* \leq 1$;

(iii) $c_e < \bar{c}_e, c_h < \bar{c}_h$: π_h is increasing in ξ_h , i.e., $\xi_h^* = 1$;

(iv) $c_e < \bar{c}_e, c_h \geq \bar{c}_h$: π_h is convex in ξ_h , and:

(a) $\xi_h^* = 1$ if $\bar{c}_h \leq c_h < \bar{c}_h(c_e)$, or (b) $\xi_h^* = 0$ if $c_h \geq \bar{c}_h(c_e)$.

Denote $\pi_h^* = \pi_h(\xi_h^*, \chi_h^*)$. Recall that c_e is the coefficient in the cost to the hospital for its efforts towards organ recovery activities, and c_h is the coefficient in the cost to the hospital from the wait times experienced by the hospital's other patients. Intuitively, when both c_e and c_h are sufficiently low (cases (iii) and (iv)a of Proposition 1), it is optimal for the hospital to exert its highest effort level (i.e., $\xi_h^* = 1$). On the other hand, when c_e and/or c_h are sufficiently high (cases (i) and (iv)b of Proposition 1), it is optimal for the hospital to not exert any effort (i.e., $\xi_h^* = 0$). However, when c_e is sufficiently high and c_h is sufficiently low (case (ii) of Proposition 1), the hospital's payoff is concave in its effort level and the optimal level of effort for the hospital could be an interior value (i.e., $0 < \xi_h^* \leq 1$).

So that the OPO's objective of volume of care is maximized, it is in the OPO's private interest for the hospital to exert the highest effort level. However, Proposition 1 points out several instances where the private incentives of the OPO and the hospital are misaligned. Restricting our focus to the nontrivial cases where $\xi_h^* > 0$, let Θ_1 denote the set of parameter conditions such that $\xi_h^* = 1$, and let Θ_2 denote the set of parameter conditions such that $0 < \xi_h^* < 1$. Also, let \tilde{f} denote the equilibrium overall fraction of potential donors who end up as authorized donors in the current scenario, i.e. $\tilde{f} = \tau \xi_h^* \xi_o^*$. Thus, \tilde{f} is either equal to $\tau\theta$ (under Θ_1) or strictly less than $\tau\theta$ (under Θ_2). Note that in the current scenario, the equilibrium fractions of both types of potential donors who end up as authorized donors, are the same; i.e., $\tilde{f}_1 = \tilde{f}_2 = \tilde{f}$ ($= \tau \xi_h^* \xi_o^*$). Next, we characterize our proposed centralized scenario wherein we examine the social planner's objective and its implications for socially-optimal actions by the hospital and the OPO.

2.4.2 Proposed Centralized Scenario: Socially-Optimal Actions

The operational actions of the OPO and the hospital: their respective effort levels and the OR scheduling policy chosen by the hospital, affect the delays experienced by authorized donors and the hospital's other patients while waiting for the OR to become available and, thus, the social planner's payoff π_S . Note that, for a given OR scheduling policy χ , the social

planner's payoff depends only on the effective fraction (f_i) of type $i \in \{1, 2\}$ potential donors who end up as authorized donors, and not the individual values of f_h and f_o (recall that f_h is the fraction of potential donors who end up as referred donors and f_o is the fraction of referred donors who end up as authorized donors). The social planner's payoff in (2) can be rewritten as: $\pi_S(f_1, f_2, \chi) = \lambda_h Q_h[1 - q_h w_h(f_1, f_2, \chi)] + f_1 \lambda_{p1} Q_{a1}[1 - q_a w_{a1}(f_1, f_2, \chi)] + f_2 \lambda_{p2} Q_{a2}[1 - q_a w_{a2}(f_1, f_2, \chi)]$.

Under the proposed centralized scenario, the hospital will be required to prioritize among *three* classes of patients competing for OR access, namely, type 1 authorized donors ($a1$), type 2 authorized donors ($a2$), and the hospital's other patients (h). Let \mathcal{A}_S denote the set of possible OR scheduling policies for these three classes of patients. The vector $\{w_{a1}, w_{a2}, w_h\}$ of average wait times experienced by the three classes of patients are characterized by Equations (2.5) and (2.6) (Gelenbe and Mitrani 1980). We reasonably assume that the mean ($\frac{1}{\mu_a}$), and second moment (ν_a) of the service time in the OR is same for both classes ($a1$ and $a2$) of authorized donors (e.g., Brockmann et al. 2006). Denote $\rho_{ai} = \frac{f_i \lambda_{pi}}{\mu_a}$, where $i \in \{1, 2\}$.

$$w_y \geq \frac{f_1 \lambda_{p1} \nu_a + f_2 \lambda_{p2} \nu_a + \lambda_h \nu_h}{2(1 - \rho_y)}, \quad y \in \{a1, a2, h\} \quad (2.5)$$

$$\rho_{a1} w_{a1} + \rho_{a2} w_{a2} + \rho_h w_h = (\rho_{a1} + \rho_{a2} + \rho_h) \frac{f_1 \lambda_{p1} \nu_a + f_2 \lambda_{p2} \nu_a + \lambda_h \nu_h}{2(1 - \rho_{a1} - \rho_{a2} - \rho_h)} \quad (2.6)$$

Under the proposed centralized scenario, $\chi = I$ denotes that the hospital gives priority to class $a1$ and $a2$ patients over class h patients. Under Assumption A1, given the hospital's choice of OR priority between authorized donors and the hospital's other patients, it turns out that the relative priority between the two classes of authorized donors has a negligible impact on their wait times in the OR queue because $w_{a1}(f_1, f_2, \chi) \cong w_{a2}(f_1, f_2, \chi)$. Furthermore, since $w_{ai}(f_1, f_2, \chi) > w_{ai}(f_1, f_2, I) \quad \forall \chi \in \mathcal{A}_S \setminus \{I\}, i \in \{1, 2\}$, the social planner's payoff is higher if the hospital prioritizes authorized donors over its other patients. In other words, the socially-optimal OR scheduling policy (denoted by χ^S) is I , which is at odds with the

hospital's privately-optimal OR scheduling policy ($\chi_h^* = II$; see Section 2.4.1).

The social planner is faced with a *quantity-quality* trade-off. A larger fraction of either type of potential donors converted to authorized donors (i.e., higher *quantity*) also leads to greater OR congestion, which results in longer wait times in the OR queue for both types of authorized donors as well as the hospital's other patients. The longer wait times faced by authorized donors in the OR queue adversely impact QALY outcomes (i.e., lower *quality*). Thus, from the social planner's perspective, it is valuable to understand how efforts should be allocated between the two types of potential donors. Proposition 2 characterizes the socially-optimal fractions of type 1 and type 2 potential donors who should end up as authorized donors, based on the characteristic q_a of the focal organ. Recall that q_a is the sensitivity of QALYs added for the organ recipient, to the delay experienced by the organ donor while waiting in the OR queue.

Proposition 2. *With a higher OR priority for authorized donors over the hospital's other patients, $\exists \bar{q}_a > 0$ and $\bar{\bar{q}}_a > 0$, such that the following three cases characterize the socially-optimal fractions, f_1^S and f_2^S , respectively, of type 1 and type 2 potential donors who should end up as authorized donors:*

$$\begin{aligned} (i) \quad q_a < \bar{q}_a: \quad & f_1^S = \tau\theta, \quad f_2^S = \tau\theta; \\ (ii) \quad \bar{q}_a \leq q_a < \bar{\bar{q}}_a: \quad & f_1^S = \tau\theta, \quad f_2^S = \max \left\{ \frac{(1-\rho_h)[Q_{a1}(2-q_a\lambda_h\nu_h-q_a\tau\theta\lambda_{p1}\nu_a)-Q_{a2}q_a\tau\theta\lambda_{p1}\nu_a]-Q_hq_h\lambda_h\nu_a}{2Q_{a1}(1-\rho_h)q_a\lambda_{p2}\nu_a}, 0 \right\}; \\ (iii) \quad q_a \geq \bar{\bar{q}}_a: \quad & f_1^S = \min \left\{ \frac{(1-\rho_h)Q_{a1}(2-q_a\lambda_h\nu_h)-Q_hq_h\lambda_h\nu_a}{2Q_{a1}(1-\rho_h)q_a\lambda_{p1}\nu_a}, \tau\theta \right\}, \quad f_2^S = 0. \end{aligned}$$

Denote $\pi_S^S = \pi_S(f_1^S, f_2^S, \chi^S)$. From Proposition 2, we observe that it is always optimal for the social planner to first allocate ODVC resources to convert type 1 potential donors to authorized donors, and then to allocate any remaining resources to convert type 2 potential donors to authorized donors. This result is intuitive given that the focal organ recovered from a type 1 potential donor adds more QALYs for the organ recipient as compared to the focal organ recovered from a type 2 potential donor.

Note that the upper limit on the OPO's effort level, in essence, places an upper limit ($= \tau\theta\lambda_p$) on the overall rate of authorized donors that can be achieved by the ODVC.

Proposition 2 points out cases where it is *not* socially optimal to exhaust the available resources of the supply-side ODVC players; i.e., under certain conditions, $f_1^S \lambda_{p1} + f_2^S \lambda_{p2}$ is strictly less than $\tau \theta \lambda_p$. For instance, when the QALYs added to the organ recipient is highly sensitive to the delay experienced by the organ donor in the OR queue (i.e., q_a is higher), it is socially optimal for all type 1 potential donors to end up as authorized donors; however, it is *not* socially optimal to exhaust the remaining resources to convert all possible type 2 potential donors to authorized donors (i.e., cases (ii) and (iii) in Proposition 2). This is because a larger fraction of type 2 authorized donors increases OR congestion and, hence, adversely affects the QALYs added for the recipients of organs from both types of potential donors – including the recipients of type 1 organs. This observation is pertinent because, despite the scarcity of organs, 10% of livers and similarly high percentages of other types of organs are turned down by transplant surgeons during or after organ recovery surgery in the OR because of concerns regarding organ quality (Colpart et al. 1999). In other words, there exists opportunity for improvement in the allocation of scarce resources based on potential-donor types.

Proposition 2 points out several instances where $f_1^S \leq \tilde{f}_1$ or $f_2^S \leq \tilde{f}_2$, i.e., that the equilibrium fractions that result in the current scenario are not socially optimal. Consider the following two cases: (i) $\tilde{f}_i > f_i^S \forall i \in \{1, 2\}$. For example, a sufficiently large q_a would lead to this relationship. In this case, it is socially optimal for the hospital or the OPO to exert a lower effort level than in the current scenario due to the adverse effect on OR congestion and, hence, on QALY outcomes. However, this would conflict with the OPO's volume-of-care objective, and, possibly, the hospital's objective. (ii) $\tilde{f}_i < f_i^S \forall i \in \{1, 2\}$. For example, a sufficiently small q_a would lead to this relationship. Since the OPO always exerts its maximum effort level (i.e., $\xi_o^* = \theta$), in this case, it is socially optimal for the hospital to exert greater effort than in the current scenario in order to increase the rate of authorized donors, although this would not be privately optimal for the hospital.

The problem at hand can be viewed as a principal-agent problem, wherein a contract

needs to be designed if the social planner (principal) intends for the hospital and the OPO (agents) to make operational decisions that would lead to the socially-optimal fractions of type 1 and type 2 potential donors being converted to authorized donors. Contracts can be designed that either: (i) directly specify the OPO’s level of effort, and the hospital’s level of effort and OR scheduling policy, or (ii) alter the objectives of the OPO and the hospital to induce the desired operational actions and, thus, organ recovery outcomes. We focus on the latter because OPOs operate under a federal mandate that requires them to collect data on missed referrals by hospitals and time stamps related to key organ recovery milestones (e.g., administration of various medical tests and drugs, intra-hospital transfers, etc.). Before discussing the design of socially-optimal contracts, we present a numerical illustration that is grounded in practice, in order to reinforce the context of our analysis thus far.

2.4.3 Numerical Illustration

Using numerical values that are grounded in practice, we illustrate current misalignments in the objectives of the social planner, the OPO, and the hospital. We use the following representative values for our model parameters based on the medical literature and interviews with OPO staff:

- (i) $\lambda_h = 400$ patients per month (based on the number of OR procedures at a large donor hospital in the OPO’s DSA; AHD 2016), and $\rho_h = 0.8$ (based on estimates reported in the set of studies reviewed by Cardoen et al. 2010, p. 924).⁴
- (ii) According to the medical literature, kidney transplants add about 4.7 QALYs for recipients, as compared to about 0.8 QALYs added by hip arthroplasty and 0.66 QALYs added by bypass surgery (CEAR 2017, Held et al. 2016). Accordingly, we use $\frac{Q_{a1}}{Q_h} = 6$. Also, since transplants of expanded-criteria or marginal-quality kidneys add about 15% fewer QALYs in contrast to non-expanded-criteria kidneys (Ojo 2005), we use $\frac{Q_{a2}}{Q_{a1}} = 0.85$.

⁴Our findings are qualitatively similar if we instead consider a lower ρ_h (say, equal to 0.6).

(iii) Based on data provided by OPO staff for kidneys, $\lambda_p = 12$ per month, $R_{af} = 200,000$ USD per donor, and $R_{av} = 2,000$ USD per donor per day. Also, we use $\lambda_{p2} = 4$ per month (on average, marginal donors constitute approximately 30-34% of all kidney donors; Klein et al. 2010), and $\frac{1}{\mu_a} = 4$ hours (LifeSource 2016).

We assume that $\theta = 1$ and $\tau = 0.8$, and choose appropriate values for the remaining model parameters (c_h , c_e , ν_a , and ν_h) in order to examine the conditions discussed in Section 2.4.1: (a) Conditions Θ_1 : A sufficiently low c_e and a sufficiently low c_h lead to $\xi_h^* = 1$, in which case, $\tilde{f}_1 = \tilde{f}_2 = \tilde{f} = \tau \xi_h^* \xi_o^* = 0.8$; and (b) Conditions Θ_2 : A sufficiently high c_e and a sufficiently low c_h lead to $0 < \xi_h^* < 1$. Here, we choose parameter values such that $\xi_h^* = 0.80$, in order to match the resulting value of f_h with the average referral rate reported in Sheehy et al. (2003). Thus, in this case, $\tilde{f}_1 = \tilde{f}_2 = \tilde{f} = \tau \xi_h^* \xi_o^* = 0.64$.

The socially optimal fractions of type 1 and type 2 potential donors who should end up as authorized donors, or f_1^S and f_2^S , take values according to Proposition 2 in Section 2.4.2. Based on the model parameters outlined above, we obtain $\frac{1}{q_a} \cong 25.4$ hours and $\frac{1}{\bar{q}_a} \cong 16.9$ hours. These values are in reasonable agreement with the medical literature that recommends recovery of kidneys from cadaver donors within about 24 hours of declaration of BD (e.g., Blasco et al. 2007). Figures 2.3 and 2.4 include plots of the equilibrium fractions ($\tilde{f}_1 = \tilde{f}_2 = \tilde{f}$) of potential donors who currently end up as authorized donors and the socially-optimal fractions (f_1^S and f_2^S) who should end up as authorized donors, with respect to the sensitivity (q_a) of QALYs added for the organ recipient to the delay experienced by the organ donor while waiting in the OR queue.

The plots in these figures show that, under both sets of conditions (Θ_1 and Θ_2), there exist regions wherein the equilibrium fractions in the current scenario are not socially optimal. Under Θ_1 , $f_1^S < \tilde{f}_1$ for $q_a > \bar{q}_a$ and $f_2^S < \tilde{f}_2$ for $q_a > \bar{q}_a$ (see Figure 2.3); and under Θ_2 , $f_1^S > \tilde{f}_1$ for $q_a < \bar{q}_a$ and $f_2^S > \tilde{f}_2$ for $q_a < \bar{q}_a$ (see Figure 2.4). Thus, the numerical illustration highlights the realistic possibility of the incentive misalignments discussed in Section 2.4.2.

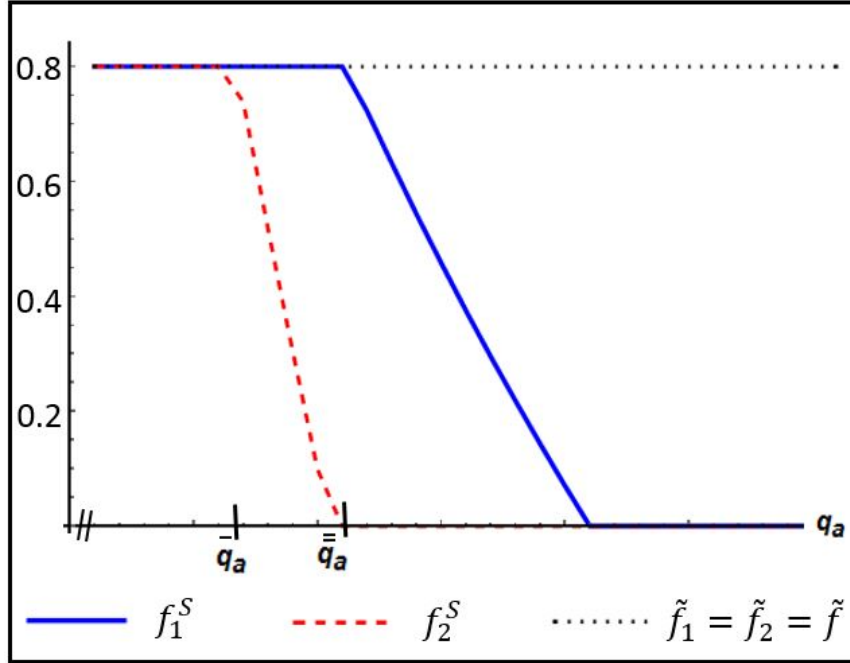


Figure 2.3: Numerical Illustration (Under Conditions Θ_1)

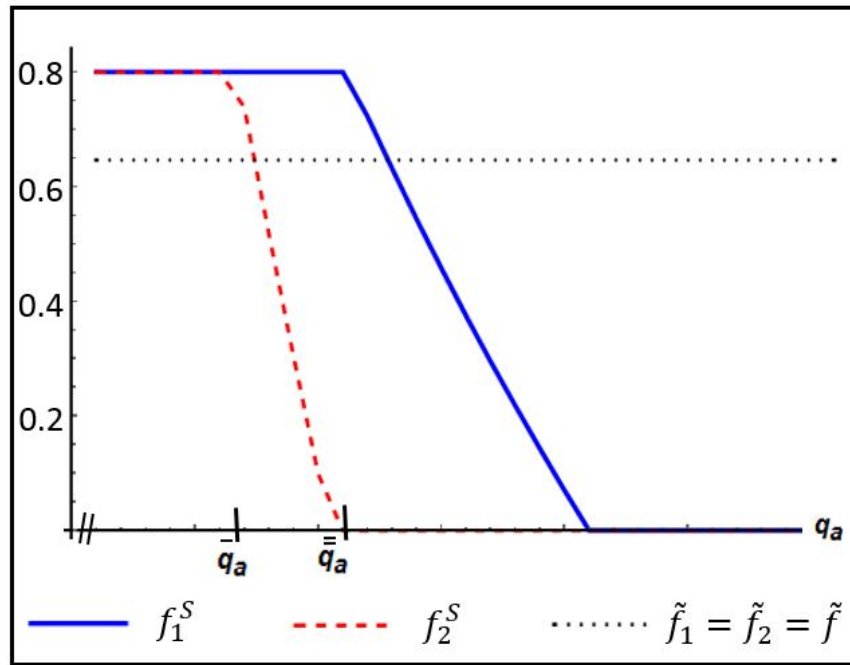


Figure 2.4: Numerical Illustration (Under Conditions Θ_2)

2.5 Socially Optimal Contracts

We propose a multiparameter contract to address the misalignments between the social planner's objective, and the OPO's and hospital's objectives. With regard to the OPO, the social planner needs to incentivize the OPO to also take into account donor heterogeneity and the adverse impact of OR congestion on the hospital's other patients. Accordingly, we recommend that the social planner revise the OPO's objective function ($\hat{\pi}_{opo}$) to be based on composite criteria. Specifically, the OPO's revised objective function in (2.7) below comprises: (i) QALY-weighted volume components corresponding to each type of potential donors, and (ii) a suitably-weighted ($\alpha > 0$) volume-based component that addresses the adverse impact on QALYs added for the hospital's other patients.

$$\hat{\pi}_{opo} = f_1 \lambda_{p1} Q_{a1} (1 - q_a w_{a1}) + f_2 \lambda_{p2} Q_{a2} (1 - q_a w_{a2}) - \alpha (f_1 \lambda_{p1} + f_2 \lambda_{p2}) \quad (2.7)$$

With the revised objective function, the OPO would be required to differentiate its operational actions based on donor heterogeneity; therefore, $f_i = \tau \xi_h \xi_{oi}$, where $\xi_{oi} \in [0, \theta_i]$ and $0 < \theta_i \leq 1$; $i \in \{1, 2\}$. Per CMS Ruling 45 CFR §164.512(h), once a referral call is made to the OPO, the assigned OPO personnel can access medical records (e.g., health history and test results) of the potential donor. Based on this information, the OPO can *a priori* determine the potential donor's type. Let $\hat{\xi}_{oi}^*$ denote the OPO's effort level for type i potential donors referred by the hospital, that maximizes $\hat{\pi}_{opo}$.

Next, we suggest that the social planner levy the following two penalties on the hospital: (i) a penalty (at rate p_m) on the hospital for each missed referral, and (ii) a penalty (at rate p_d per unit wait time) on the hospital for the average wait time experienced by type 1 authorized donors in excess of the average wait time for them under the proposed centralized

scenario (see Section 2.4.2). With these penalties, the hospital's revised payoff is:

$$\hat{\pi}_h = \lambda_a R_{af} + (f_1 \lambda_{p1} w_{a1} + f_2 \lambda_{p2} w_{a2}) R_{av} + \lambda_h R_h - c_h w_h - \frac{c_e}{2} \xi_h^2 - \lambda_p (1 - f_h) p_m - (w_{a1} - w_{a1}^S) p_d \quad (2.8)$$

Where, $\lambda_a = \tau \xi_h (\xi_{o1} \lambda_{p1} + \xi_{o2} \lambda_{p2})$ and $w_{a1}^S := w_{a1}(f_1^S, f_2^S, \chi^S)$. We denote the hospital's optimal effort level and OR scheduling policy under the contract by $\hat{\xi}_h^*$ and $\hat{\chi}_h^*$, respectively. Denote $\hat{\pi}_h^* = \hat{\pi}_h(\hat{\xi}_h^*, \hat{\chi}_h^*)$.

In practice, hospitals do not bear any financial penalties for adverse ODVC performance outcomes, except maybe for annotations in accreditation reports prepared by federal agencies such as the Joint Commission on Accreditation of Healthcare Organizations, for choosing suboptimal organ recovery effort levels that lead to missed referrals (see the DHHS report by Inspector General Brown 2000; p. 19–20). This DHHS report recommends that some kind of mechanism (incentive or disincentive) be implemented based on data that is already being collected, in order to improve hospitals' compliance with the donation rule. However, no such mechanism exists in practice. OPOs already audit patient records of hospitals in their respective DSAs at regular intervals (monthly or quarterly) to collect data on missed referrals and time stamps related to key organ recovery milestones, so there would be limited additional administration costs for implementing these penalties based on missed referrals and wait times experienced by type 1 authorized donors. There are other examples of penalties that have been introduced to influence the operational actions of hospitals and improve societal outcomes. One example is the Readmission Penalty that was introduced by CMS in 2012 to curb the loss in quality of care and substantial costs incurred due to avoidable re-hospitalizations of Medicare beneficiaries (Berenson et al. 2012, CMS 2012). A few recent studies have analyzed the effects of this penalty on hospitals' operational actions such as readmission-reduction efforts (Andritsos and Tang 2015, Zhang et al. 2016). Another example is the Hospital-Acquired Condition (HAC) Reduction Program introduced by CMS in 2014, that penalizes hospitals that perform poorly on HAC quality measures (CMS 2014).

The set of contractual levers $\{\alpha, p_m, p_d\}$ outlined above can help the ODVC attain the socially optimal payoff π_S^S (see Section 2.4.2) and, when appropriately specified, can even ensure that both the OPO and the hospital are strictly better-off with the implementation of the contract. For the hospital, strictly better-off implies that its equilibrium payoff under the contract attains a larger value compared to the current (uncoordinated) scenario. For the OPO, strictly better-off means that its total equilibrium effort under the contract ($= \hat{\xi}_{o1}^* + \hat{\xi}_{o2}^*$) is less than $2\xi_o^*$, where ξ_o^* is the OPO's equilibrium effort for each type of potential donors under the current scenario (see Section 2.4.1). Note that the factor of 2 in the aforementioned comparison arises because, under the current scenario we have $f_1 = f_2 = \tau\xi_h\xi_o$, and under the contract we have $f_1 = \tau\xi_h\xi_{o1}$ and $f_2 = \tau\xi_h\xi_{o2}$.

We focus on Pareto-improving contracts for their promise of acceptability. In our context, Pareto improvement implies that none of the three entities, namely, the OPO, the hospital, or the social planner is worse-off, and at least one of them is strictly better-off with the implementation of the contract. The suggested contractual levers in Proposition 3 not only influence the operational actions of the hospital and the OPO to help the ODVC achieve socially-optimal performance, but also achieve strict Pareto improvement for the OPO and the hospital.

Proposition 3. $\exists \bar{p}_m > 0$ and $\bar{p}_d > 0$ s.t. $\forall p_m > \bar{p}_m, p_d > \bar{p}_d$, and $\alpha = \frac{Q_h q_h \lambda_h \nu_a}{2(1-\rho_h)}$, the set of contractual levers $\{\alpha, p_m, p_d\}$ ensures: (i) Social optimality, i.e., $\hat{\pi}_S(\alpha, p_m, p_d) = \pi_S^S$ and, (ii) Strict Pareto improvement for the hospital and the OPO, i.e., $\hat{\pi}_h^* > \pi_h^*$ and $\hat{\xi}_{o1}^* + \hat{\xi}_{o2}^* < 2\xi_o^*$.

As stated in Section 2.4.2 (proposed centralized scenario), the OR scheduling policies that are respectively optimal for the social planner and the hospital, are divergent ($\chi_S^S = I$ and $\chi_h^* = II$). Under the revised objective function for the hospital, choosing $p_d > \bar{p}_d$ ensures that the hospital accords absolute priority to authorized donors over its other patients, i.e., $\hat{\chi}_h^* = I$ (see Proof of Proposition 3). Recall that the OPO is the Stackelberg follower. An appropriately-chosen weight α in the OPO's revised objective function ensures that the OPO

adjusts its effort levels for both types of referred donors in response to the hospital's chosen effort level, thereby balancing QALY outcomes across organ recipients and the hospital's other patients. The social planner can always choose a value of p_m such that $\hat{\xi}_{o1}^* + \hat{\xi}_{o2}^* < 2\xi_o^*$, so that the OPO is strictly better-off under the contractual mechanism in Proposition 3 as compared to the current scenario.

Setting α and p_d as in Proposition 3, effectively fixes the overall fraction (f) of potential donors who end up as authorized donors because $\lambda_a = f_1^S \lambda_{p1} + f_2^S \lambda_{p2}$, which implies that $f = \frac{f_1^S \lambda_{p1} + f_2^S \lambda_{p2}}{\lambda_{p1} + \lambda_{p2}}$. If the penalty for missed referrals (p_m) were zero, the hospital's payoff would be decreasing in ξ_h , implying that the equilibrium effort level of the hospital under the contract would be zero. By levying a penalty ($p_m > 0$) on the hospital for missed referrals, the social planner induces an interesting dynamic between the OPO and the hospital. In the presence of a non-zero penalty for missed referrals, it becomes costly for the hospital to not exert effort towards organ recovery activities. However, because of the presence of the QALY-based components in the OPO's revised objective, the OPO (Stackelberg follower) responds to an increased effort level by the hospital by substantially reducing its own effort levels for type 1 and/or type 2 potential donors referred by the hospital. The resulting equilibrium decisions of the OPO and the hospital end up being beneficial for the hospital because of decreased OR congestion and, hence, lower wait times experienced by the hospital's other patients. The reduced OR congestion also favorably impacts QALY outcomes and helps the ODVC achieve socially-optimal performance.

2.6 Conclusion

While the majority of the healthcare operations management literature focuses on the demand side of the ODVC, we develop an analytical model to study the effects of contextual parameters and operational actions of the supply-side entities (OPO and hospital) on their respective payoffs and on societal outcomes. Our analysis of the current (uncoordinated) and proposed centralized scenarios reveals several key findings. *First*, we show that higher

effort levels towards organ recovery activities chosen by either the OPO or the hospital have counteracting effects on the societal outcome (assessed based on quality-adjusted life years, or QALYs). Although higher effort levels lead to larger fractions of conversions of potential donors to authorized donors, another resulting effect is greater congestion at the OR. Consequently, authorized donors as well as the hospital’s other patients experience longer wait times in the OR queue, resulting in adverse impacts on QALY outcomes.

Second, in contrast to current ODVC policies and practices that do not require the hospital or the OPO to differentiate their operational actions based on the quality of organs that can be recovered from potential donors, our analysis shows that the social planner’s objective may be non-monotonic in the respective fractions of the different types of potential donors who end up as authorized donors. Using a numerical illustration that is grounded in practice, we demonstrate the realistic possibility of incentive misalignments between the social planner, and the OPO and hospital. These misalignments lead to socially suboptimal fractions of organs recovered from the different types of potential donors.

Third, we recommend a multiparameter contract to address the misalignments between the social planner’s objective, and the OPO’s and hospital’s objectives. We show that by: (i) including QALY-based components corresponding to each type of potential donors and an appropriately-weighted volume-based component in the OPO objective (i.e., revising the OPO’s objective to reflect composite criteria); and (ii) levying appropriately-chosen penalties on the hospital for missed referrals and for socially suboptimal delays experienced by authorized donors while waiting for the OR to become available; the social planner can help the ODVC achieve not only socially-optimal performance, but also strict Pareto improvement for the OPO and the hospital. This contractual mechanism is administratively feasible since OPOs already collect data on missed referrals by hospitals and time stamps related to key organ recovery milestones, and it also has the promise of acceptability since no player would be worse-off.

Under our recommended contractual mechanism, it may be possible for the resource-

constrained OPO to increase the allocation of its efforts towards accomplishing other important tasks, such as fundraising, public awareness campaigns, and community engagement. Also, the OPO may be able to allocate more effort towards assisting hospital staff in lowering their discomfort associated with organ donation activities (e.g., through training programs on cultural sensitivities towards organ donation, psychological support skills to enhance end-of-life care, etc.; DOT Grant Program Report 2005). As an example, New England Organ Bank, the OPO for the six New England states, has instituted educational programs for HCPs on psychological support skills in discussions surrounding death and dying, that have led to a significant increase in the number of referrals of potential donors by hospitals in its DSA.

Consistent with studies that consider principal-agent problems in the non-profit and healthcare contexts (e.g., Devalkar et al. 2016, Gupta and Mehrotra 2015), we consider that the social planner (the principal), strives to optimize the benefit delivered to organ recipients and the hospital’s other patients. Thus, in our setting, the social planner’s payoff is different from the sum of the payoffs of the individual players. However, our results remain structurally similar if we add the hospital’s and OPO’s objectives within the social planner’s payoff. Also, in our work, we consider the hospital to be a profit-maximizing entity. Although empirical studies (Deneffe and Masson 2002, Duggan 2000) find that not-for-profit hospitals behave in a similar manner as profit-maximizing entities, including in the context of ODVCs (Rios-Diaz et al. 2017), if the hospital too had a volume-of-care component in its objective, the incentive misalignments would be less severe and the interventions from the social planner for both the OPO and the hospital would be in the form of composite criteria (i.e., QALY-based components added to the existing objective). Apart from contractual levers, our model points to other potentially viable operational interventions for improving organ recovery outcomes: expanding OR capacity (increasing μ), improving the waiting experience in the OR queue (decreasing c_h), and emphasizing HCP training to reduce the discomfort associated with organ recovery activities (decreasing c_e).

With regard to limitations of our work and avenues for future research, we note that our model focuses on one focal organ whereas multiple organs can potentially be recovered from a cadaveric donor. It will be interesting to study the privately- and socially-optimal levels of efforts by the OPO and the hospital, as well as the OR priorities accorded by the hospital in the presence of heterogeneity in organ yields across potential donors or heterogeneity in the characteristics of organs (e.g., sensitivities of different organs to delays experienced by the donors). Also, as discussed earlier, the existing OM literature focuses on the demand side of the ODVC whereas our work adds to the sparse literature on the supply side. We believe that there will be value in capturing the interplay between demand- and supply-side actions in order to further improve societal outcomes. For instance, it will be valuable to study the interplay between the operational actions in the organ recovery process and the trade-offs involved in the allocation of organs to patients on the waitlist.

CHAPTER 3

WHEN DO APPOINTMENTS OF CORPORATE SUSTAINABILITY EXECUTIVES AFFECT SHAREHOLDER VALUE?

3.1 Introduction

Over the last two decades, firms have been appointing sustainability executives to be part of their top management teams (TMTs). Denning (2011) labels this trend as “sustainability reaching the C-suite,” and attributes it to the breadth, complexity and rapid evolution of sustainability issues. The number of firms with sustainability executives in TMTs doubled between 1995 and 2003, and again between 2003 and 2008 (Greenbiz 2013). Indeed, Forbes (2016) lists “sustainability leadership” that combines operational efficiency with optimal resource use as one of the top four supply chain career paths for 2025. Titles for sustainability executives include Chief Sustainability Officer, Chief Responsibility Officer, Corporate Social and Environmental Officer, and Executive or Senior Vice-President of Sustainability, etc. (Strand 2012). For the purpose of our study, we refer to these executives as Corporate Sustainability Executives (CSEs). Further, we draw on the prior literature (for instance, Kleindorfer et al. 2005, Chen and Delmas 2011) to adopt the following definition of sustainable practices: A set of management practices that allow a firm to minimize negative impacts and maximize positive impacts of its operations on the environment and on the society (including employees and community).

There is an extensive body of literature investigating the shareholder value effects of firms’ socially and environmentally responsible actions such as philanthropy and equal employment opportunities citepmargolis2003; environmental management in the form of process redesign, investment in new environmental technologies, and reduction in emissions of hazardous pollutants into the natural environment (Klassen and McLaughlin 1996, King and Lenox 2002);

ISO 14000 certification (Corbett and Kirsch 2001); environmental initiatives and awards (Jacobs et al. 2010); and corporate social responsibility (CSR) communications (Yu et al. 2013). The work by Flammer (2013; 2015) posits that engagement in eco-friendly corporate initiatives generates new and competitive resources for the firm, and finds a positive stock market reaction when firms announce eco-friendly initiatives or pass CSR-related proposals in their annual board meetings. Godfrey et al. (2009) find that sustainability initiatives help develop goodwill and trust that insure the firm against socially and environmentally negative events. Research has also established a positive link between CSR engagements of a firm and its environmental and social performance (Kroes et al. 2012, Toffel and Short 2011). Although there is a vast literature on CSR practices and strategies and their relationships with various measures of firm performance, little is known about the nature of the empirical link between CSE appointments and financial performance.

A closely-related empirical study linking CSE appointments and financial performance that we are aware of is by Wiengarten et al. (2017), who examine the association between appointments of chief officers of corporate social responsibility and improvement in operating performance as measured by change in return on assets. We add to the understanding of this link between CSE appointments and financial performance by using a stock price-based performance measure. More specifically, we examine the stock market reaction attributable to announcements of CSE appointments. We also investigate how the stock market reaction depends on the following firm- and industry-specific factors: (i) whether the responsibilities specified for the CSE appointee are focused versus broad; (ii) appointments announced subsequent to an adverse sustainability-related event; (iii) sustainability-related performance of the announcing firm; and (iv) the level of regulatory sanctions experienced by the industry in which the announcing firm operates.

The TMT of a firm comprises a group of executives who are usually one or two levels below the CEO and are responsible for formulating, propagating, and executing the corporate strategy of the firm. Given that these executives have a strong influence in firms' strate-

gic decision-making, it is of interest to study when appointments to TMTs affect financial performance. The extant literature has examined stock market reactions to appointments of senior executives in various functional areas, including Chief Financial Officers (CFOs; Mian 2001), Chief Marketing Officers (CMOs; Boyd et al. 2010, Nath and Mahajan 2008), Chief Information Officers (CIOs; Chatterjee et al. 2001), and Supply Chain and Operations Management Executives (SCOMEs; Hendricks et al. 2015). We contribute to this literature by examining the stock market reaction to appointments of CSEs.

Our empirical analyses are based on a sample of 111 announcements of CSE appointments made by publicly listed firms over the period 2000–2016. We find that the stock market reaction to CSE appointments is insignificantly different from zero, indicating that such appointments are overall value-neutral. Our finding is encouraging in the sense that it suggests that these appointments, which are intended to help improve firms’ social and environmental performance, do not hurt shareholder value. Although the stock market reaction to CSE appointments is overall value neutral, we find that the stock market reacts more positively under certain firm- and industry-specific conditions.

In particular, we find evidence of a more positive market reaction when announcing firms specify focused as opposed to broad responsibilities for the CSE appointee. On average, firms announcing CSE appointments with focused responsibilities have a 0.92% higher mean market reaction as compared to firms announcing CSE appointments with broad responsibilities. We also find evidence of a more positive market reaction in instances where the announcing firms faced a prior adverse sustainability-related event. Firms faced with an adverse sustainability-related event in the year prior to the announcement of CSE appointment, have a 0.74% higher mean market reaction relative to announcing firms that did not face such an event. Furthermore, we find evidence of a less positive market reaction when announcing firms operate in industries that face higher levels of regulatory sanctions. Firms operating in industries experiencing higher levels of regulatory sanctions, have a 0.55% lower mean market reaction when compared to announcing firms that operate in industries with

lower levels of regulatory sanctions. However, the stock market reactions are not different between announcements by firms with weaker versus stronger sustainability performance. Our findings continue to hold when we account for potential self-selection bias, and are robust to alternative methods of estimating stock market reaction.

The remainder of the chapter is organized as follows. Section 3.2 presents the related theory and develops our hypotheses. Section 3.3 describes our sample of announcements of CSE appointments. Section 3.4 outlines the methodology that we use to estimate the stock market reactions to the announcements and to test our hypotheses. Section 3.5 presents our results, and discusses the implications of our findings. Section 3.6 summarizes the chapter and suggests directions for future research. All tables are included in Appendix C.

3.2 Theory and Hypotheses

In this section, we begin by reviewing the relevant theory that examines link between sustainability and financial performance of the firm. We next highlight the role of CSEs within TMTs, and then present specific arguments for developing our hypotheses of the relationships between firm- and industry-specific factors and the stock market reactions to CSE appointments.

The early literature posited a negative relationship between a firm’s engagement in sustainability practices and its financial performance (Friedman 1970, McGuire et al. 1988). Based on neoclassical economic theory, this literature argued that costs outweigh the economic benefits of a sustainability-focused corporate strategy. However, several subsequent research studies challenged this view by arguing that corporate sustainability efforts enable the firm to: *(a) decrease costs* – for example, by reducing waste, improving process efficiency, and helping retain employees, *(b) increase revenues* – for example, by improving brand image, reputation, and trust and opening up new markets (socially-conscious or “green” consumers), *(c) mitigate internal and external risks* – for example, by ensuring safe working conditions and reducing emissions of hazardous pollutants into the natural envi-

ronment, and (d) *enhance competitiveness* – for example, by offering differentiated products (e.g., environmentally-friendly product designs), and improving consumer sentiment (Berry and Rondinelli 1998, Lee and Klassen 2008, Porter and van der Lind 1995, Sroufe 2003).

A steady increase in the frequency of introduction of federal environmental laws and amendments, scrutiny by the media and NGOs, push for human rights, demand for improved workplace diversity policies, and green initiatives implemented by other firms, has led to a concomitant increase in sustainability-related pressures on firms. However, a barrier to the adoption of sustainability initiatives is lack of top management commitment (Epstein et al. 2010, Blass et al. 2014). In particular, Blass et al. (2014) suggest that lack of top management commitment can impede the adoption of energy efficiency practices because non-TMT members typically do not have sufficient access to information across business units and are unable to reallocate resources. The literature has established that strong support and conviction from a firm’s leadership and the creation of a CSE position in the TMT provide stimulus for sustainability-related changes across the firm’s business units (Chinander 2001, Eccles et al. 2012).

As the primary executive in the TMT with responsibility over the firm’s sustainability strategy, a CSE can make the business case for resource allocations that ensure an effective integration of sustainability within the firm’s corporate strategy. Through the power of being a TMT member, a CSE can also ensure that the sustainability commitment trickles down from higher management through middle management to ground-level employees. Additionally, the elevated representation of sustainability at the TMT level can be expected to improve the ability of the firm to exploit synergies among its business units (Guadalupe et al. 2013). For instance, David E. Kepler, citing an experience related to the development of alternate fuels, stated that – as Dow Chemical’s Chief Sustainability Officer – his opinion carried substantial weight among the technology, manufacturing, and finance teams involved in the firm’s strategic decision making (Deutsch 2007). In sum, a CSE can influence corporate decisions to increase the effectiveness of sustainability practices and initiatives, which

can eventually help reduce costs and improve revenues for the firm. Furthermore, a CSE can liaise with various external stakeholders (such as regulatory agencies, NGOs and environmental and social activists) to mitigate risks such as legal actions, cleanup costs, and reputation loss.

While the preceding discussion sheds light on how presence of a CSE in the TMT can lead to financial benefits and enhanced competitiveness for the firm, the literature offers minimal guidance regarding the shareholder value effects of appointing CSEs. Our study adds to this nascent literature by investigating relationships between firm- and industry-specific factors and the stock market reactions to CSE appointments.

Hypotheses Development

Our first hypothesis pertains to the specification of focused versus broad responsibilities for the CSE position. Longworth et al. (2012) outline the typical responsibilities of sustainability-related executives in TMTs based on a survey of 25 global companies. These responsibilities include ensuring access to sustainability expertise and knowledge across the firm's business units, developing a transformational corporate sustainability strategy, monitoring external sustainability issues for the business (such as regulations and compliance), and communicating the firm's sustainability strategy to its stakeholders. We posit that the stock market reaction is more positive when firms announce CSE appointments with focused as compared to broad responsibilities, for three reasons.

First, specification of focused responsibilities for the CSE position helps reduce ambiguity about the firm's expectations for the appointee. Given the technical and managerial complexities associated with the sustainability function, there are challenges in aligning sustainability initiatives with organizational practices (Ansari et al. 2010, Corbett and Klassen 2006). These challenges may lead investors to face uncertainty as to the ways through which the appointed CSE will help improve the firm's sustainability and financial performance. Adequate role information, specific goal content, and clearly communicated expectations help reduce uncertainty about the firm's expectations for the CSE appointee (Kahn et al.

1964, Latham and Locke 1995).

Second, focused, as compared to broadly-specified responsibilities is indicative of the firm paying closer attention to fit among the sustainability objectives of the firm, the skills of the appointee, and organizational resources. Bansal et al. (2014) underscore that the fit between a firm’s sustainability strategy and its competitive resources plays an important role in determining firm financial performance. Additionally, amidst “greenwashing” concerns, a firm’s announcement of CSE appointment may be seen as another ruse to influence public perception about the firm’s sustainability strategy. However, the specification of focused as opposed to broad responsibilities for a CSE may more credibly signal to stakeholders the firm’s intent to follow through with sustainability initiatives.

Finally, several research studies, including Nath and Mahajan (2011) and Smith and Tushman (2005), have proposed that a well-defined role for a TMT member along with a clear alignment of responsibilities with goals, enable the TMT member to have more effective control over resources and, thus, greater organizational power. Accordingly, the specification of focused as opposed to broad responsibilities for the CSE position can be expected to elevate the appointee’s organizational power. In turn, drawing from the political view of organizations (Cyert and March 1963, Pfeffer 1981), CSEs with greater organizational power can ensure a better alignment of sustainability decisions with corporate strategy, resulting in a more positive impact on a firm’s financial performance.

Accordingly, we hypothesize the following:

HYPOTHESIS H1. *The stock market reacts more positively to announcements of CSE appointments that specify focused as compared to broad responsibilities for the appointee.*

Our next hypothesis pertains to the stock market reaction to announcements of appointments to CSE positions depending on whether or not the announcing firms faced a prior adverse sustainability-related event. Adverse sustainability-related events faced by announcing firms may include eco-harmful incidents (e.g., chemical spills), violations of federal environmental laws, and occupational safety and health incidents resulting in death and/or

significant property damage. The occurrence of such an event raises concerns about the firm's commitment to the environment and society, requiring the firm to send a credible signal to stakeholders regarding its commitment toward sustainability (Hardcopf et al. 2016).

Announcing appointment of a new CSE subsequent to an adverse sustainability-related event signals a focus on damage control and loss minimization by the firm, as well as renewed corporate-level focus on the management of liabilities, reputation losses, and wasted resources associated with the occurrence of such events. The appointment of a new CSE may also reflect the TMT's commitment to not only undertake remedial measures but also employ a proactive sustainability strategy that helps avoid future adverse events or noncompliance. Further, a prior adverse sustainability-related event attracts significant additional pressures from the firm's stakeholders, which are likely to be relieved upon the firm's appointment of a new CSE. In the wake of this stricter monitoring by NGOs, the media, and environmental and social activists, who demand an increased focus on sustainability (Wood and Schneider 2006), appointing a new CSE can demonstrate a strong intent to rebuild relationships with these stakeholders. These arguments lead to the following hypothesis:

HYPOTHESIS H2. *The stock market reacts more positively to announcements of CSE appointments by firms that faced a prior adverse sustainability-related event, as compared to announcements by firms that did not face such an event.*

Our third hypothesis pertains to the stock market reaction to announcements of appointments to CSE positions depending on the firm's sustainability performance. A firm's sustainability performance can be measured by the firm's strengths along several dimensions such as the environment, diversity, and human rights (Chen and Delmas 2011). The literature has established that a firm's current sustainability performance is a significant determinant of the value that it can derive from introducing additional sustainability practices and strategies. For instance, Hart and Ahuja (1996) find evidence of diminishing returns to investments for improving environmental performance. Further, Flammer (2013) finds that firms with better environmental performance benefit less from the introduction of an

additional green initiative. This is because, while it might be easy and worthwhile for firms to implement sustainable practices and strategies in the early stages, value gains from the implementation of subsequent practices will be lower.

Based on the preceding discussion, we argue that, at a firm with weaker sustainability performance, it is less challenging for the newly-appointed CSE to convince other decision makers to better align existing resources or allocate resources to implement additional socially and environmentally responsible initiatives. The announcement of CSE appointment by a firm with weaker, as opposed to stronger, sustainability performance conveys to stakeholders that the firm will be able to derive higher value gains from subsequent sustainable practices, which would further improve the firm's financial performance. Accordingly, we propose the following hypothesis:

HYPOTHESIS H3. *The stock market reacts more positively to announcements of CSE appointments by firms with weaker sustainability performance.*

Our final hypothesis pertains to levels of sustainability-related regulatory sanctions experienced by the industry in which the announcing firm operates. It is plausible that an announcement of CSE appointment by a firm operating in an industry that faces greater regulatory sanctions may be an indication that the firm is seeking to be more proactive in mitigating risks such as legal actions, cleanup costs, and reputation loss. However, the literature has argued that stakeholders' expectations are a function of norms and standards originating from the firm's affiliated networks (Romanelli and Khessina 2005), and a firm's practices and strategies are influenced by the industry that they operate in (Hawawini et al. 2003). We posit that announcements of CSE appointments by firms operating in industries that face higher levels of regulatory sanctions would be associated with less positive stock market reaction, for the following two reasons.

First, we argue that stakeholders are more likely to view the firm's intent to announce appointment of CSE with a higher degree of skepticism when it operates in an industry that faces higher levels of sustainability-related regulatory sanctions. Barnett and King

(2008) find that an industry is perceived as “illegitimate” when firms in the industry indulge in major and repeated undesirable sustainability-related actions. They suggest that, more often than not, stakeholders (including shareholders, customers, the government, the media, and environmental and social activists) are unable to discriminate between the firms in an industry that do meet regulatory standards and those that do not. Similarly, Diestre and Rajagopalan (2011) argue that greater regulatory sanctions on an industry imply that firms in that industry are unable or unwilling to meet prevailing regulatory standards. We invoke a similar logic to propose that an announcement of CSE appointment by a firm operating in an industry with greater regulatory sanctions will send potentially weaker information to stakeholders about the firm’s enhanced commitment to sustainability and motivation to undertake sustainability initiatives.

Second, research on attention and impression-formation suggests that a particular action attracts attention if it is perceived as novel or unusual relative to the others in the same group (Jones and McGillis 1976, Skowronski and Carlston 1987). Additionally, the extent of media attention and scrutiny on individual firms is weaker when more firms from the same group (industry) are viewed as negligent in terms of their sustainability-related practices and actions (Zavyalova et al. 2012). We extend this argument to claim that an announcement of CSE appointment by a firm operating in an industry that experiences lower levels of regulatory sanctions will be viewed as unanticipated and novel for that industry, when compared to the announcement by a firm operating in an industry that experiences higher levels of regulatory sanctions. Thus, in the latter scenario, the announcement will provide a stronger signal to stakeholders reinforcing the firm’s commitment to sustainability

Based on the above discussion, we hypothesize the following:

HYPOTHESIS H4. *The stock market reacts less positively to announcements of CSE appointments by firms operating in industries that face greater regulatory sanctions.*

3.3 Sample

As an initial step towards collecting announcements of CSE appointments, we used a preliminary set of search keywords to identify a set of CSE announcements from different business dailies and newswire services. We read these announcements to identify additional phrases and words that are commonly used in announcements of CSE appointments. The final set of keywords that we used was: (“chief” or “president” or “executive” or “director” or “head”) and (“sustainability” or “environmental” or “social” or “responsibility”), and their variants with different ending letters. We searched the headlines and lead paragraphs of all announcements in the *Wall Street Journal (WSJ)*, *Dow Jones News Service (DJNS)*, *PR Newswire (PRN)*, and *Business Wire (BW)* during 2000–2016 and obtained 303 announcements of CSE appointments. We followed the following steps to generate our final sample of announcements:

- Given that our focus is on examining stock market reaction, we restrict our sample to announcements made by publicly traded firms. We excluded firms that do not have stock price information available from the University of Chicago’s Center for Research in Security Prices (CRSP) US Stock Databases. Of the 303 announcements, 193 were made by firms that had stock price information available from CRSP.
- We excluded announcements that reported two or more simultaneous personnel changes. For example, one announcement mentioned that, in addition to a CSE appointment, the firm was also appointing a new CIO. We exclude such announcements to avoid the conflation of the effects of simultaneous events on the stock market reaction. Out of the 193 announcements, 63 reported two or more simultaneous personnel changes and were therefore excluded.
- We excluded CSE announcements for firms that had confounding events around the announcement date – specifically, announcements of CEO appointments and earnings

announcements by the same firm. For this, we searched our sources for contemporaneous announcements by the firm within a five-day window (± 2 trading days) around the CSE announcement date (Boyd et al. 2010, Jacobs and Singhal 2017). Of the 130 announcements, 19 had contemporaneous announcements and were therefore excluded.

Thus, our final sample comprises 111 announcements of CSE appointments. Some examples include:

- “Exide Technologies, a global leader in stored electrical-energy solutions, announced today that Mark W. Cummings will join the Company as Vice President-Global Environmental, Health & Safety, effective July 25” (Business Wire 2005).
- “AEGON has appointed Executive Vice President Marc van Weede as global Head of Sustainability, reporting to CEO Alex Wynaendts” (PR Newswire 2010a).
- “Smithfield Foods, Inc. today announced that it has promoted Dennis H. Treacy to senior vice president of corporate affairs and chief sustainability officer as part of the company’s long-term focus on corporate social responsibility and sustainability” (PR Newswire 2010b).

Before presenting further description of our sample of announcements, it will be useful to provide a better understanding of the significance of the CSE position. We briefly discuss the specific responsibilities, the external activities, and the backgrounds of the CSE appointees in our data. To obtain the requisite information, we searched the LinkedIn profiles of the CSE appointees¹ as well as archived communications pertaining to the appointees on the respective company websites. Our analysis of the information (which was available in the needed detail for 69 out of the 111 CSE appointees in our sample) revealed significant responsibilities, including: leading the development and accomplishment of corporate sustainability strategy and goals; leading the integration of sustainability innovations and practices across

¹From the LinkedIn profile of the CSE appointee, we collected information (such as job description) listed under the job title/position that is mentioned in the corresponding announcement in our sample.

business functions and departments; leading environmental and social sustainability efforts along the dimensions of energy, water, emissions, safety, social initiatives, and transparency; overseeing compliance with local, state, and federal laws; and liaising with key global customers, investors, the media, academic organizations, environmental advocacy groups, and NGOs.

The backgrounds of these CSE appointees were also noteworthy, and included: former positions of high seniority within or outside the company; former positions as environmental directors/administrators/advisors at the city/state/federal/international levels (including reporting directly to former US Presidents, and advising the OECD, UN, USAID, and the British Prime Minister’s Office on matters of sustainable development and environmental policy); leadership/board membership at companies and flagship industry associations, non-profits, and NGOs (such as the National Mining Association, US Green Building Council, Oak Ridge Center for Advanced Studies, and Environmental Council of the States); and recipients of city/state/national awards for public service.

Sample Description

Most announcements in our sample provide information about demographics of the CSE appointee and nature of the CSE position. Table C.1 summarizes this information. Approximately 30% of CSE appointees in our sample are women. This is significantly higher than the percentage of women SCOMEs (7%) reported by Hendricks et al. (2015). For 73.0% of the sample, information about the educational background of the appointed CSE was available within the announcement. For another 24.3% of the sample, we were able to collect information on educational backgrounds by accessing the profiles of the CSE appointees on LinkedIn. We were unable to obtain information on educational backgrounds for the remaining 2.7% of the sample. The highest educational degree for 30.6% of the CSEs is a bachelor’s degree, for 55.0% it is a master’s degree, and for 14.4% it is a Ph.D. 28.8% of the CSE appointees have an MBA degree. For 61.3% of the announcements in our sample, information about the number of years of work experience for the appointed CSE was available;

the mean (median) prior work experience of the CSE appointees was 22 (21) years.

In our sample, the percentage of appointments to newly-created CSE positions (45%) is slightly less than the percentage of appointments to existing CSE positions (55%). For comparison with other C-level appointments, 66% of the CMO positions during 1996–2005 in the sample in citeboyd2010 were newly created. However, only 12% of the CFO positions during 1984–1997 in the sample in Mian (2001) were newly created and 29% of the SCOME positions during 2000–2011 in the sample in Hendricks et al. (2015) were newly created. Additionally, in our sample, there is an almost even split between appointments of outsiders (48.6%) and insiders (51.4%) to CSE positions. The percentage of outsider CSEs is lower than that of outsider CMOs (73%) reported by Boyd et al. (2010) and outsider SCOMEs (67%) reported by Hendricks et al. (2015) but is similar to the percentage of outsider CFOs (50%) reported by Mian (2001). For 53.8% of the announcements in our sample, information was provided on whom the CSE appointee would report to. 30.6% of the CSE appointees in our sample were stated as reporting directly to the firm’s CEO or COO.

Table C.2 provides statistics on size and financial performance of the announcing firms. The mean (median) market value of equity of the announcing firms in our sample is \$30.9 (9.1) billion, with a standard deviation of \$75.6 billion. Table C.3 summarizes the number of appointments by year-range. A relatively higher proportion of announcements are in the middle year ranges (2004–2007 and 2008–2011) of the time period considered in our study. The mean (median) number of announcements per year is 6.5 (6). Table C.4 summarizes three broad industry groups based on ranges of Standard Industrial Classification (SIC) codes. The majority of the announcements in our sample (72.1%) are from the manufacturing industries (SIC codes 2000 to 4999), including, food, paper, chemicals, rubber, metals, automobile, and aircraft; 18% are from wholesaling, retailing, and services (SIC codes 5000 to 9999); and 9.9% are from agriculture and resource-extracting industries (SIC codes 0001 to 1999).

3.4 Methodology

This section discusses the methodology and statistical tests that we use for estimating the stock market reactions to the announcements of CSE appointments, and describes the methodology and empirical model that we use to test the hypotheses introduced in Section 3.2.

3.4.1 Estimating Stock Market Reactions: Abnormal Returns

We use event study methodology to estimate the stock market reactions to the announcements of CSE appointments. This methodology estimates the stock market reaction (referred to as “abnormal” returns) to an event, while adjusting for market-wide and other factors that may influence stock returns (see Brown and Warner 1985). The abnormal returns are an estimate of the percent change in stock price associated with an event. The basis of event study methodology is that, in an efficient market, the shareholder value effects of an event are immediately reflected in the stock price.

All announcements in our sample first appeared in either *DJNS*, *PRN*, or *BW* and indicate the time when the announcement was publicly released. We use the time of release of information to determine the announcement date. If the announcement was released before 4:00 p.m. EST, then no adjustment is necessary to the announcement date. If the announcement was released after 4:00 p.m. EST, we set the announcement date as the next trading day, when investors can act on the information contained in the announcement. For instance, the announcement of Northwest Natural Gas Company’s CSE appointment was publicly released at 7:38 p.m. EST on June 1, 2006 (Business Wire 2006). Thus, we set June 2, 2006 as the announcement day for this announcement. We translate calendar days into event days such that the announcement day is Day 0, Day 1 is the trading day following the announcement day, Day -1 is the trading day before the announcement day, and so on. We use the announcement day, or Day 0, as the (one-day) event period to measure the stock

market reaction.

Consistent with recent event studies (e.g., Flammer 2015, Hendricks et al. 2015), we use the Four-Factor model to estimate abnormal returns. The Four-Factor model incorporates the market return factor, size factor, book-to-market factor, and the momentum factor (Fama and French 1993, Carhart 1997). The Four-Factor model posits a linear relationship between the stock return and the four factors over a given time period, as:

$$R_{it} = \alpha_i + R_{ft} + \beta_{i1}[R_{mt} - R_{ft}] + \beta_{i2}SMB_t + \beta_{i3}HML_t + \beta_{i4}UMD_t + \epsilon_{it}. \quad (3.1)$$

Where R_{it} is the return of stock i on Day t , α_i is the intercept of the relationship for stock i , R_{ft} is the risk-free return on Day t , R_{mt} is the market return on Day t , SMB_t is the small-minus-big size portfolio return on Day t , HML_t is the high-minus-low book-to-market portfolio return on Day t , UMD_t is the past-one-year winner-minus-loser stock portfolio return (the momentum factor) on Day t , and ϵ_{it} is the error term for stock i on Day t . To compute the expected return for each announcing firm, we estimate $\hat{\alpha}_i$, $\hat{\beta}_{i1}$, $\hat{\beta}_{i2}$, $\hat{\beta}_{i3}$, $\hat{\beta}_{i4}$, and $\hat{S}_{\epsilon_i}^2$ (the variance of the error term ϵ_{it}) using ordinary least squares regression over the estimation period of 200 trading days; we begin the estimation period from Day -210 and end it on Day -11. We end the estimation period 10 trading days prior to the event day to shield the estimates from possible effects related to the announcement and to avoid non-stationarities in the estimates. Also, we require that a firm must have a minimum of 40 days of stock returns data during the 200-day estimation period. The abnormal return A_{it} for firm i on Day t is computed as the difference between the actual and the expected return:

$$A_{it} = R_{it} - \left(\hat{\alpha}_i + R_{ft} + \hat{\beta}_{i1}[R_{mt} - R_{ft}] + \hat{\beta}_{i2}SMB_t + \hat{\beta}_{i3}HML_t + \hat{\beta}_{i4}UMD_t \right). \quad (3.2)$$

The mean abnormal return, \bar{A}_t , for Day t is given by:

$$\bar{A}_t = \sum_{i=1}^N \frac{A_{it}}{N}, \quad (3.3)$$

where N is the number of announcements in the sample. To test the statistical significance of the mean abnormal return (given by Equation (3.3)), we use the standardized abnormal returns obtained by dividing each abnormal return A_{it} by its standard deviation $\hat{S}_{\epsilon i}$. Under the null hypothesis (that the abnormal returns are not significantly different from zero) and the Central Limit Theorem, the mean abnormal return for Day t (\bar{A}_t) is approximately Normal with mean 0 and variance $\hat{S}_{\epsilon i}^2$. The test statistic TS_t for Day t is calculated as follows:

$$TS_t = \sum_{i=1}^N \frac{A_{it}/\hat{S}_{\epsilon i}}{\sqrt{N}}, \quad (3.4)$$

We use the t -test to determine the statistical significance of the mean abnormal return. To check for the influence of outliers, we supplement the t -test with the following two non-parametric tests: (i) Wilcoxon signed-rank test, to test for the statistical significance of the median abnormal return, and (ii) Binomial sign test, to determine if the percent positive abnormal returns during the event period is significantly greater than the null of 50%. All reported p -values are two-tailed.

3.4.2 Methodology for Testing Hypotheses

To test our hypotheses, we regress the announcement day (Day 0) abnormal returns on the explanatory and control variables. We use the following explanatory variables to represent H1 through H4.

- *Focused* = 1 if the firm specified focused responsibilities for the appointed CSE in the announcement, 0 otherwise. Based on a content analysis of the announcements in our sample, we classified the stated responsibilities of the CSE appointee into the following five categories: (i) Ensuring regulatory compliance; (ii) Ensuring occupational and

environmental safety and health; (iii) Communicating with key stakeholders; (iv) Developing corporate sustainability strategy; and (v) Building the firm’s sustainability vision and goals. Table C.5 presents the distribution of announcements based on these categories.² Each announcement in our sample states at least one of these five categories of responsibilities for the CSE appointee. We consider the responsibilities for the CSE to be focused as opposed to broad if the firm only specified one or more of the first three categories (ensuring regulatory compliance, ensuring occupational and environmental safety and health, and communicating with key stakeholders) listed above. This categorization is consistent with the extant literature on goal specificity, which suggests that “specific,” as opposed to “vague,” responsibilities constitute well-outlined goals or outcomes, well-articulated performance evaluation metrics, and precise reference states (Larson and Schaumann 1993, Latham and Locke 1995, Locke et al. 1989). Accordingly, 45 (66) announcements in our sample specified focused (broad) responsibilities for the CSE appointee.

- *Prior_Event* = 1 if the announcing firm faced an adverse sustainability-related event within the year prior to the announcement of CSE appointment, 0 otherwise. To identify prior adverse sustainability-related events, we searched the headlines and lead paragraphs of all articles in *WSJ*, *DJNS*, *PRN*, and *BW* that mention the announcing firm within a 365-day period prior to the announcement of CSE appointment. Some examples of prior adverse sustainability-related events include the following: “...violated federal law by failing to share and provide access to health and safety information to its workers...,” “...Nuclear Regulatory Commission imposes safety penalty due to violation of subject matter expert (SME) guidelines...,” “...charged by the Federal government for Clean Air Act violation...” 36 out of the 111 announcing firms faced adverse sustainability-related event(s) within the year prior to their respective announcement of CSE appointment. The mean (median) number of days between the latest ad-

²The sum exceeds 100% because multiple categories may be specified within an announcement.

verse sustainability-related events for the announcing firms and their respective CSE announcements is 92 (36) days.

- *Sust_Performance* = 1 if the firm has a relatively weaker sustainability performance, 0 otherwise. For this measure, we use data from Kinder, Lydenberg, and Domini, Inc. (KLD) Research & Analytics, which is a private entity that rates firms on a scale of 0 (no particular strength) to 7 (a high strength) in a variety of sustainability-related dimensions. Consistent with Flammer (2013) and the related literature, we construct a composite index by summing the firm’s strengths in the fiscal year prior to the announcement of CSE appointment on the following six dimensions: *employee relations, environment, product, community, diversity, and human rights*. The KLD database does not have the required information for 19 firms in our sample. For the remaining 92 firms, we consider that the firm has a weaker sustainability performance (*Sust_Performance* = 1) if the composite score is below our sample’s median of 3, and *Sust_Performance* = 0 if the composite score is at or above the sample median.
- *Reg_Sanctions* = 1 if the firm operates in an industry that experiences relatively higher levels of regulatory sanctions, 0 otherwise. For this measure, we collected data from the US Environmental Protection Agency’s (EPA’s) Enforcement and Compliance History Online (<http://echo.epa.gov/>) on the total value of fines imposed by the EPA in a particular industry (4-digit SIC levels) in the most recent fiscal year that ended prior to the announcement date of CSE appointment. Consistent with recent studies such as Diestre and Rajagopalan (2011; 2014), we consider that a greater level of industry fines administered by the EPA implies that firms in that industry are unable or unwilling to meet prevailing sustainability-related regulatory standards. We normalize the monetary amount of fines by the number of firms in that industry in the year prior to the announcement (obtained using data from the US Census Bureau). Thus, for each announcing firm, we obtain the following measure for the fiscal year

prior to the announcement:³

$$\text{Industry-level Regulatory Sanctions} = \frac{\text{Industry-level Fines by the EPA}}{\text{Number of Firms in the Industry}}. \quad (3.5)$$

We consider a firm to be operating in an industry that experiences relatively greater regulatory sanctions ($Reg_Sanctions = 1$) if the measure given by Equation (3.5) for the firm’s industry (4-digit SIC) is at or above the sample median of \$189,678 per firm, 0 otherwise.

Control Variables: Consistent with previous event studies that examine the relationships between appointments to TMTs and stock market reactions (Mian 2001, Boyd et al. 2010, Hendricks et al. 2015), we control for a set of factors that may influence the stock market reaction to announcements of CSE appointments. Specifically,

- $New = 1$ if the CSE is appointed to a newly-created position, 0 otherwise.
- $Outsider = 1$ if an outsider is appointed to the CSE position, 0 otherwise.
- $Firm_Size$, to control for the size of the announcing firm. We measure $Firm_Size$ as the natural logarithm of the firm’s market value of equity (in Million USD) in the most recent fiscal year that ended prior to the announcement date.
- $CEO_Turnover = 1$ if the firm changed its CEO within 12 months before the date of CSE appointment. We reviewed annual reports, and company press releases during the year of and the fiscal year prior to the date of CSE appointment in order to ascertain whether the firm changed its CEO. In 17 of the 111 CSE appointments in our sample (approximately 15%), a new CEO was appointed by the firm within 12 months of its announcement of CSE appointment.

³The results are qualitatively similar if we instead use: (i) total number of industry fines in the numerator in Equation (3.5), or (ii) average of “Industry-level Regulatory Sanctions” over a three-year period prior to the announcement.

We use the following model specification to test our hypotheses:

$$AR_i = \beta_0 + \beta_1 Focused_i + \beta_2 Prior_Event_i + \beta_3 Sust_Performance_i + \beta_4 Reg_Sanctions_i \\ + \beta_5 New_i + \beta_6 Outsider_i + \beta_7 Firm_Size_i + \beta_8 CEO_Turnover_i + \epsilon_i, \quad (3.6)$$

where ϵ_i is the error term. The predicted signs of coefficients β_1 , β_2 , and β_3 are positive, whereas the predicted sign of coefficient β_4 is negative.

3.5 Results and Implications

In this section, we present our findings for the overall stock market reaction to our sample of CSE appointments), followed by results of our hypotheses tests. We discuss the implications of our findings and compare them to the findings in the literature for appointments of other types of senior executives.

3.5.1 Overall Stock Market Reaction to CSE Appointments

Table C.6 presents the abnormal returns for the one-day event period (announcement day, or Day 0) for our sample of 111 announcements of CSE appointments. The mean (median) abnormal return is -0.05% (-0.18%), not significantly different from zero. Approximately 46% of the announcements in our sample have positive stock market reactions, insignificantly different from 50%. The results are similar if we use the Market Model and the Market-Adjusted Model (Brown and Warner 1985) instead of the Four-Factor Model to estimate abnormal returns. The results are also similar if we consider [Day 0, Day 1], [Day -1, Day 0], or [Day -1, Day 1] as the event period instead of Day 0, or if we estimate abnormal returns using 150 days or 250 days as the estimation period instead of 200 days.

While the results suggest mixed shareholder assessments of CSE appointments, it is encouraging to observe that, overall, the appointments *do not hurt* shareholder value. It is instructive to compare the stock market reaction to the CSE appointments in our study

with the stock market reactions to appointments of other types of senior executives. While Hendricks et al. (2015) find that the mean abnormal return for SCOME appointments is 0.24%, significantly different from zero, Mian (2001) finds that the mean abnormal stock return for CFO appointments is -0.05% , not significantly different from zero. Also, Boyd et al. (2010) find that the mean abnormal stock return for announcements of CMO appointments is 0.003% , not significantly different from zero.

Our finding that the stock market reaction to CSE appointments is value-neutral, is in contrast to the finding in Wiengarten et al. (2017) that appointments of chief officers of corporate social responsibility are associated with improved return on assets in the fiscal year after the announcement of CSE appointment. More importantly, as discussed next, the results of our hypotheses tests show that the stock market reacts more positively under certain firm- and industry-specific factors.

3.5.2 Results of Hypotheses Tests

We use multivariate regressions to test our hypotheses. Table C.7 presents the regression coefficients with t -statistics in parentheses. Model 1 includes only the three explanatory variables for which we have data available for all 111 announcements – *Focused* (whether the responsibilities specified for the CSE appointee are focused as opposed to broad), *Prior_Event* (whether an adverse sustainability-related event preceded the announcement of CSE appointment), and *Reg_Sanctions* (whether the announcing firm operates in an industry with relatively greater levels of regulatory sanctions). When we include the fourth explanatory variable, i.e., *Sust_Performance* (whether the announcing firm has a relatively weaker sustainability performance), we lose 19 observations because the KLD database does not have the required information for these announcing firms. Model 2 includes the four explanatory variables, and Model 3 includes all explanatory and control variables.

From the results for Model 3, we observe the following: *First*, the estimated coefficient of *Focused* is positive and significantly different from zero. Announcements specifying focused

responsibilities for the CSE appointee have a 0.92% higher mean market reaction compared to appointments specifying broad responsibilities.

Second, the estimated coefficient of *Prior_Event* is positive and significantly different from zero. Thus, we find evidence that the stock market reacts more positively (0.74% higher mean market reaction) if the announcing firm faced an adverse sustainability-related event in the year prior to the announcement of CSE appointment. However, it is plausible that the stock market reacts more positively essentially to compensate the announcing firms for potential negative stock market reactions to announcements of the prior adverse sustainability-related events. To examine this further, we estimate the stock market reactions, on the announcement day of the adverse sustainability-related events, for the 36 firms in our sample that faced such an event in the year prior to the announcement of CSE appointment. We find that the mean stock market reaction is -0.14% , which is sufficiently lower than the mean stock market reaction (0.59%) to announcements of CSE appointments by these 36 firms. This further suggests that appointment of a new CSE may be perceived as a sign of the firm's commitment to adopt a proactive sustainability strategy that helps avoid future adverse events or noncompliance.

Third, the estimated coefficient of *Sust_Performance* is positive but not significantly different from zero. Although Flammer (2015) finds that the stock market reaction to the passing of CSR-related proposals is more positive for firms with weaker sustainability performance, our finding suggests that stock market reactions are not different between announcements of CSE appointments by firms with weaker versus stronger sustainability performance.

Fourth, the estimated coefficient of *Reg_Sanctions* is negative and significantly different from zero. Announcements made by firms operating in industries that experience higher levels of regulatory sanctions have a 0.55% lower mean market reaction compared to appointments by firms in industries that face lower regulatory sanctions. The results continue to hold if we use a tercile-split instead of the median-split to define industries that experience

low (0), moderate (1), or high (2) regulatory sanctions (indicated by 0, 1, and 2 respectively).

Finally, we do not find evidence of an association between our control variables and the stock market reaction to announcements of CSE appointments. The estimated coefficient of *New* is positive but not significantly different from zero. This finding is similar to the finding for announcements of CMO appointments in Boyd et al. (2010). Similarly, the estimated coefficient of *Outsider* is positive but not significantly different from zero. While Hendricks et al. (2015) find that the stock market reacts more positively when the SCOME appointee is an outsider rather than an insider, our finding is similar to that in Mian (2001) wherein the stock market reactions are not significantly different between announcements of CFO hires from outside versus inside the firm.

Although the estimated coefficient of *Firm_Size* is negative, it is statistically not significant.⁴ Further, we find that the stock market reaction is not significantly impacted by CEO turnover within the 12-month period prior to the announcement of CSE appointment.

3.5.3 Accounting for Self-Selection

Given that the firms in our sample have self-selected to announce CSE appointments, our sample is nonrandom, thereby raising concerns of endogeneity. To account for potential self-selection bias, we employ the Heckman two-step procedure (Heckman 1979, Maddala 1983). In the first step, we use a selection model to predict the likelihood of a firm announcing the appointment of a CSE, and estimate the Inverse Mills Ratio (IMR). In the second step, we use a regression model that includes the IMR as an additional explanatory variable.

Matching Sample. We follow Hendricks et al. (2015) and Kalaighnam et al. (2013) to identify a set of firms that did not announce a CSE appointment (could be either because a CSE appointment did not occur or that a CSE appointment that did occur was not announced). For each firm in our sample, we find a matching firm outside of our sample

⁴Other measures of firm size, such as sales and total assets are typically highly correlated with market value of equity. For instance, in our sample, the correlation between firms' market value of equity and sales is 0.8. All results reported in Sections 3.5.1, 3.5.3, and 3.5.4 continue to hold if we instead measure *Firm_Size* as the natural logarithm of sales in the most recent fiscal year that ended prior to the announcement date.

with the same 4-digit SIC code and closest to the sample firm in terms of market value of equity at the end of the fiscal year prior to the announcement of CSE appointment by the sample firm.

Selection Model. To the best of our knowledge, there is no literature that has identified factors that could influence the propensity to announce the appointment of a CSE. A few practitioner survey studies, which document the backgrounds and roles of CSEs, suggest that as sustainability gains prominence within the firm and across the industry, the appointment of CSE becomes strategically valuable for the firm (e.g., Denning 2011, Weinreb 2011). As an example, Scott Wicker, the first Chief Sustainability Officer of UPS, mentioned that his position was created in response to several internal and external pressures “due to the increased complexity of sustainability reporting and enhanced accountability for regulatory non-compliance” (Weinreb 2011). We use the firm’s performance on the six sustainability-related dimensions in the KLD data, and the level of regulatory sanctions faced by the industry in which the firm operates as measures of the prominence of sustainability within the firm and across the industry, respectively. Accordingly, we include *Sust_Performance* and *Reg_Sanctions* in our selection model.

In addition, the literature on discretionary disclosures by firms about their sustainability efforts has shown that firm size and profitability, together with sustainability performance, influence the propensity of firms to disclose such information (e.g., Baumann-Pauly et al. 2013, Reverte 2009, Verrecchia 1983). Furthermore, the literature on CEO turnover has identified firm size and prior financial performance as the two most commonly used explanatory variables for the selection model (e.g., Warner et al. 1988, Parrino et al. 2003). Drawing on these literature streams, we therefore include the natural logarithm of market value of equity (*Firm_Size*) and return on assets (*ROA*) in the fiscal year that ended prior to the announcement of CSE appointment by the sample firm in our selection model. Thus, our

first-stage selection model is:

$$\Pr(CSE_Announcement_i = 1) = \Phi(\beta_0 + \beta_1 Firm_Size_i + \beta_2 ROA_i + \beta_3 Sust_Performance_i + \beta_4 Reg_Sanctions_i + \epsilon_i). \quad (3.7)$$

The selection model is significant with a log likelihood of -121.8 (p -value < 0.025).⁵ The results for the selection model indicate that firms with a higher market value of equity (i.e., larger firm size) or lower return on assets (i.e., poorer prior financial performance) are significantly more likely to announce CSE appointments.

Regression Model with IMR. Our second-stage regression model is:

$$AR_i = \beta_0 + \beta_1 Focused_i + \beta_2 Prior_Event_i + \beta_3 Sust_Performance_i + \beta_4 Reg_Sanctions_i + \beta_5 New_i + \beta_6 Outsider_i + \beta_7 Firm_Size_i + \beta_8 CEO_Turnover_i + \beta_9 IMR_i + \epsilon_i. \quad (3.8)$$

Model 4 in Table C.7 shows the regression results for the model specified in Equation (3.8). The coefficient for IMR is not significant, suggesting that our sample does not exhibit self-selection bias. The results of Model 4 are very similar to the results of Model 3.

3.5.4 Robustness Checks

We conduct the following additional analyses to establish the robustness of the results reported in Section 3.5.2. *First*, we examine the robustness of our findings to the method used to compute abnormal returns. Recall that the results reported in Section 3.5.2 are based on announcement-day abnormal returns estimated using the Four-Factor Model (Model 3 in Table C.7). In Models 1 and 2 in Table C.8, we estimate announcement-day abnormal returns using the Market Model and the Market-Adjusted Model, respectively, and find similar results (with the only exception of the significance of the coefficient for *Reg_Sanctions*

⁵As noted earlier, the KLD database does not have the required information for 19 announcing firms in our sample. Therefore, the results of the selection model are based on 184 firms (92 sample and 92 matching firms).

in Model 1 in Table C.8).

Second, we examine the robustness of our findings to the choice of the time period used to determine the occurrence of a prior adverse sustainability-related event. The results in Table C.7 are based on a time-period of 365 days prior to the announcement of CSE appointment. The results (Model 3 in Table C.8) are qualitatively consistent if we instead use 180 days as the time-period.

Third, we examine the robustness of our results to the choice of sustainability-related dimensions included in the composite measure *Sust_Performance*. The results (Model 4 in Table C.8) are qualitatively similar if we instead use the firm’s score on only the *environment* dimension in the KLD database for the *Sust_Performance* measure.

Fourth, we examine the robustness of our results to the inclusion of additional controls in our regression model. The results are similar if we include dummies corresponding to the year ranges in Table C.3 (Model 5 in Table C.8), or the gender of CSE appointees (Model 6 in Table C.8).

3.6 Summary

In this chapter, we use event study methodology to estimate the stock market reactions to a sample of 111 announcements of CSE appointments made by publicly listed firms during the period 2000–2016. We investigate how the effect of announcements of CSE appointments on shareholder value depends on following firm- and industry-specific factors: focused- versus broadly-specified responsibilities for the CSE appointee, appointments announced subsequent to an adverse sustainability event, sustainability-related performance of the announcing firms, and the level of regulatory sanctions experienced by the industry in which the announcing firm operates.

The evidence suggests that although, on average, the shareholder value effect of CSE appointments is not significantly different from zero, the stock market reacts more positively under certain firm- and industry-specific conditions. We find that the stock market reac-

tion is more positive when firms announce CSE appointments with focused as compared to broad responsibilities. The stock market also reacts more positively in instances where the announcing firms faced a prior adverse sustainability-related event. Furthermore, we find evidence of a less positive market reaction when announcing firms operate in industries that face higher levels of regulatory sanctions. However, the stock market reactions are not different between announcements by firms with weaker versus stronger sustainability performance. Our findings demonstrate nuances in the market reactions to CSE appointments depending on various firm- and industry-specific factors, thereby enabling executives and stakeholders to better understand the shareholder value effects of appointing CSEs to TMTs.

An interesting extension of our work would be to analyze the nature of the sustainability practices implemented by the firms in our study subsequent to CSE appointment (e.g., adoption of environmental management systems, investments in green technologies, modifications in criteria for supplier evaluation, etc.). Future research could also delve further into the demographics of the CSE appointees and link them to firm performance: characteristics of interest may include number of years and diversity of experience, and educational background.

CHAPTER 4

BALANCING ADVISORY AND SERVICE DELIVERY EFFORTS IN NONPROFITS: A SERVICE DESIGN PERSPECTIVE

4.1 Introduction

Non-profit organizations (NPOs) that support and serve distressed individuals are often the last resort for those who are seeking relief from predicaments, such as domestic abuse or homelessness. These types of societal issues have large economic repercussions. For instance, victims of domestic violence lose a total of 8 million days of paid work each year in the United States, which is equivalent to a loss of \$8.3 billion per year (Rothman et al. 2007); they are also more vulnerable to depression, suicidal behavior, and HIV infection (World Health Organization 2013). Similarly, homelessness puts a significant burden on society in the form of costs associated with shelter services, which has been estimated to be nearly \$10,000 per year per person (Spellman 2010), and higher rates of crime, e.g., in 2010 alone, the state of Georgia spent \$300 million in incarcerating homeless individuals (Henrichson and Delaney 2012). There are over 5,000 NPOs in the United States that provide services related to mental health and crisis intervention, civil rights and advocacy, and employment search and training (National Center for Charitable Statistics 2013).

These NPOs provide care, money, education, shelter, and support, typically through significant personal interaction with their clients (Donovan and Jackson 1991, Hasenfeld 2009). In doing so, they face a complex combination of obstacles. First, since their clients often differ greatly in terms of their needs (Drucker 1995, Hasenfeld 2009), NPOs offer a variety of services that enable different pathways to wellness. Second, a pervasive issue faced by these NPOs is the scarcity of resources, which must be allocated to various activities (Feng and Shanthikumar 2016). Finally, and perhaps most importantly, their clients might be abjectly

unable to articulate their needs as they are unaware of the true causes of their situation (Browne 1993, Holdsworth and Tiyce 2013). This might be because these individuals have already endured traumatic experiences (Stewart et al. 2004), or exhibit symptoms of PTSD, low self-esteem, avoidance, or anxiety (Vitanza et al. 1995, Barnett 2001). As a result, many NPOs serve in an interpretive role by providing advisory support or guidance to their clients to help them receive the most appropriate services (Emanuel and Emanuel 1992).

As an illustrative example, consider Daya, a Houston, Texas-based NPO that works toward the empowerment of South Asian women who encounter domestic violence (see Section 4.6 and <http://www.dayahouston.org/> for additional details).¹ Daya offers a multitude of services ranging from counseling to shelter housing to legal support. However, because its clients are typically unable to articulate the sources of their crisis, they may seek and receive services that are not best suited to their needs. For instance, clients who need legal representation to overcome financial abuse may incorrectly seek temporary housing; while this consumes Daya's resources, it produces limited social impact.

Daya is hardly unique as an NPO that endures loss of impact from mismatches between the services its clients receive and their true needs. Georgia Works (GW) is an NPO in Atlanta, Georgia that aims to transform chronically homeless men into self-sufficient members of society (<http://www.georgiaworks.net/>). Although homelessness has many underlying causes, GW's program of rehabilitation-through-employment is successful only for clients who possess a combination of behavioral and cognitive attributes. Most of individuals who approach GW are unable to assess these characteristics by themselves. Indeed, nearly a third of the clients who participate in the GW program cannot complete the requirements. To guide clients ascertain their fitness for the program, GW spends around 12% of its overall resources on the intake process. However, given their limited amount of resources, it is not clear whether – and how much – these NPOs should invest in providing such guidance and advancing their intake processes.

¹The examples in the paper are based on interactions between the authors and the NPOs.

Motivated by the above examples, in this paper, we focus on the service design of NPOs whose clients are under-informed about their needs. Despite the practical evidence on NPOs' challenges in managing mismatches between the services clients receive and their true needs (Browne 1993, Holdsworth and Tiyce 2013), to the best of our knowledge, this is the first study to address this challenge. We propose an analytical model to answer the following research questions: *(i)* How should an NPO that serves the needs of under-informed clients design its services to create the most social impact? *(ii)* How does this service design depend on characteristics of clients' needs and services offered?

We consider an NPO's service design that comprises two types of efforts: advisory and service delivery. In the *advisory effort*, the NPO offers guidance to improve clients' understanding of their needs (e.g., a deep intake process). In the *service delivery efforts*, the NPO delivers different types of services to its clients (e.g., professional or financial rehabilitation). We characterize the NPO's optimal advisory and service delivery efforts that maximize the social impact obtained from its available resources. The optimization model captures the following trade-off: while investing in advisory effort increases the likelihood of clients receiving the appropriate services (reduces mismatches), it depletes the resources that are available for the NPO's service delivery efforts. In addition, the model captures several aspects of the state of the NPO (i.e., limited resources, scalability of its services, and differences in the social impact of its services) and clients' characteristics (i.e., mix and diversity of their needs, and loss of impact due to mismatches).

Our analysis yields several insights on managerial consequence. First, we show that when the NPO is severely resource-constrained, it should channel resources only toward its service delivery efforts; otherwise, it should spread its resources between advisory and service delivery efforts to maximize impact. Our analysis also reveals how the NPO's service design may be influenced by its *scalability*, which is an important determinant of impact for NPOs (Bradach 2003, Hurst 2012). An NPO's services may have limited scale when it faces external constraints to expansion from regional, partnership, or regulatory sources. In

such cases, we find that the NPO’s optimal advisory effort might even exceed its service delivery efforts. However, when the NPO’s services are scalable, the NPO should invest less in advisory effort, and also specialize in only a certain type of service delivery, i.e., not attempt to provide everything to everyone.

Moreover, we extend our model to investigate the impact of earmarked resources, i.e., funds donated to the NPO for only a certain type of service delivery. Our analysis shows that although earmarked funding is better than no funding at all, it may have unintended consequences for clients. Earmarked funding for one type of service can lead to an increase in investment of the NPO’s resources towards its advisory effort, but crowd out the non-earmarked service provision. We also analyze situations where the NPO’s services may not be equally scalable, or clients’ mismatches lead to different loss of impact. Finally, we provide an illustration of our analysis in a practical context and suggest opportunities for NPOs to implement our findings.

The remainder of the paper is organized as follows. In Section 4.2, we review the related literature. In Section 4.3, we present the model of an NPO’s service design problem that interrelates the characteristics of its services and clients. We present the results in Section 4.4 and extensions in Section 5. In Section 4.6, we provide a practical illustration of our findings, and in Section 4.7, we provide concluding remarks. All proofs and technical details are in Appendix D.

4.2 Literature Review

This paper is related to two streams of research: nonprofit operations management and service design. We next review these two streams of literature and position our paper accordingly.

Nonprofit Operations Management: One of the primary roles in which NPOs create societal value is by providing services for some segments of the population, especially those segments whose needs are not served by existing public sector entities or for-profit businesses

(Kramer 1981, Chapter 12). Some NPOs focus on long-lasting societal problems such as hunger and poverty. For example, food banks collect and distribute donated foods to the needy (Teron and Tarasuk 1999, Lien et al. 2014), charitable healthcare providers serve individuals with chronic diseases (Deo et al. 2013), and some medical aid organizations serve as a platform to distribute scarce drugs and supplies to regions in need (Swaminathan 2003, Atasu et al. 2017). Other NPOs focus on transient, but acute, societal problems. For instance, following disasters such as the earthquakes or hurricanes, NPOs often emerge as first respondents to serve public health (Natarajan and Swaminathan 2014) and logistical issues (Van Wassenhove 2006, Ergun et al. 2010). A common objective shared by all of these organizations is to maximize the social impact generated by their activities. In this paper, we focus on NPOs that create social impact by enabling wellness pathways for distressed and marginalized individuals. Focusing on such individuals, however, raises new challenges for these organizations.

All NPOs must overcome several hurdles in their quest to serve important social needs, and the operational nature of these hurdles may vary from one context to another (see Feng and Shanthikumar (2016) for a detailed review of the challenges faced by NPOs). For example, NPOs that provide food and therapeutics to counter health issues are routinely hampered by the limited and uncertain availability of funds (Natarajan and Swaminathan 2014, Taylor and Xiao 2014); disaster relief organizations face unpredictable infrastructure damages and availability of volunteers (Martinez et al. 2011, de la Torre et al. 2012); and medical surplus recovery organizations encounter recipients who request items they do not need (Atasu et al. 2017). To address these problems, studies on NPOs have offered innovative solutions, such as adaptations of supply chain coordination (Taylor and Xiao 2014), project management (Devalkar et al. 2017), mechanism design (Atasu et al. 2017), subsidy programs (Berenguer et al. 2017), and inventory rationing (Natarajan and Swaminathan 2017). Motivated by NPOs such as Daya and Georgia Works, we consider a new issue that has not received much attention in the literature: clients may be unable to identify services

that suit their needs, which can lead to lower overall impact generated by the NPO’s efforts. Naturally, to address this issue, NPOs can serve in an interpretive role by providing advisory support or guidance to their clients (Emanuel and Emanuel 1992). However, because such guidance does not create a direct impact and also requires resources (funds) that can also be used for other impact-creating activities, it creates a service design dilemma for these NPOs.

Service Design: There are many distinctive objectives for design of services depending on the context. These objectives include reducing customer wait time and system congestion in call centers and hospitals (e.g., Shumsky and Pinker 2003; Hasija et al. 2005; Lee et al. 2012), optimizing the sequence of service encounter in entertainment industries (Das Gupta et al. 2015, Bellos and Kavadias 2017), and maximizing the quality of services delivered in healthcare and legal consulting (Anand et al. 2011, Tong and Rajagopalan 2014). In this paper, we also focus on the service design of NPOs toward maximizing service quality, which in our context is equivalent to generating a higher social impact.

Providers can directly control the perceived quality of their services by carefully choosing the level of resources (Green et al. 2013, Lu and Lu 2017). However, unilaterally increasing efforts at a service step may not be optimal in some scenarios (Bellos and Kavadias 2017). Specifically in customer-intensive services, Anand et al. (2011) show that there is a trade-off between offering a deep experience (requiring slowness) and offering a fast and congestion-free service (requiring speed). For NPOs, the complexity of service design and improving quality (impact) arises from the scarcity of resources (Lien et al. 2014). Some NPOs have resorted to managing these constraints by allocating a portion of their service capacity to revenue-generating consumers (de Véricourt and Lobo 2009). We contribute to this literature on non-profit service design by identifying another source of complexity for NPOs: the loss of social impact due to mismatches between the services clients receive and their true needs.

In for-profit settings, Soteriou and Hadjinicola (1999) and Soteriou and Chase (2000) study resource allocation toward improving service quality, but in the context where the stages of service provision are independent and their qualities are additive (e.g., patient

satisfaction during visits to a medical clinic). An important distinction in the context that motivates our study is the interdependence between the provider’s efforts in different service stages (i.e., advisory and service delivery efforts). That is, while the NPO’s advisory and service delivery activities are complementary in generating social impact, one activity cannot be improved without adversely affecting other activities given the scarcity of resources. We therefore propose an optimal service design for NPOs whose activities are interdependent.

4.3 Model

In this section, we introduce the service design problem of an NPO that provides services to clients with different needs. The NPO has limited financial resources, denoted by $S > 0$, and has to decide on how to invest that in various client-facing activities (i.e., advisory and service delivery efforts) to maximize its overall social impact. In order to capture the differences between clients’ needs and the services offered by the NPO, we consider a simple setting with two client types, denoted by $i \in \{a, b\}$, and two service types, denoted by $j \in \{A, B\}$. The A -type (B -type) service is best suited to the service needs of a -type (b -type) clients. However, clients may seek the services that are not best suited to their needs.

Clients: We denote by $p \in (0, 1)$ the proportion of a -type clients and by $1 - p$ the proportion of b -type clients. The NPO might have a greater impact by investing the same amount of resources in serving one type of clients than the other; this, for example, may be due to differences in economic impact between the needs of clients. We define $I_i \in \mathbb{R}^+$ as a measure for the social impact that the NPO creates by investing a unit of its resources in providing the best suited service to clients of type i for $i \in \{a, b\}$. Without loss of generality, we consider $I_a \geq I_b$. Consequently, we define $k \doteq I_a/I_b \geq 1$, which we refer to as the *impact factor*.

For instance, consider Daya from our motivating example that serves about 350 clients annually. Some of Daya’s clients are suffering from physical or sexual abuse, and some others are facing some form of emotional or financial abuse. While Daya creates positive impact

by serving either types of clients, Daya will have a greater long-term economic impact on the lives of clients who face persistent psychological or financial abuse (with help provided in the form of legal services), as compared to serving those who have endured physical or sexual abuse (with relief provided in the form of housing arrangement). (See Chen (2017), McLean and Bocinski (2017), and Section 4.6 for additional details.)

Mismatch: Because clients might not be able to articulate the root causes of their needs (Browne 1993, Holdsworth and Tiyce 2013), they may seek services that are not best suited to their needs. We denote by $\alpha_{ij} \in [0, 1]$ the degree of loss of impact due to mismatches between clients' needs and services they receive for $i \in \{a, b\}$ and $j \in \{A, B\}$. For instance, when a -type clients receive the NPO's B -type service (which is not best-suited to their needs), the social impact that the NPO creates by investing a unit of its resources in such service encounters is $\alpha_{aB} \cdot I_a \leq I_a$. For simplicity of exposition, we consider $\alpha_{aB} = \alpha_{bA} = \alpha \in [0, 1]$, and refer to it as the degree of *loss of impact* due to mismatches. When there is no mismatch, $\alpha_{aA} = \alpha_{bB} = 1$. The parameter α can be interpreted as the degree of similarity in clients' needs. If the two types of clients have similar needs (α is high), the loss of impact due to mismatches is low. In contrast, when clients have significantly disparate needs (α is small), the loss of impact due to mismatch is significant. In Subsection 4.5.3, we extend our analysis to the case where the losses of impact due to mismatches are asymmetric (i.e., a -type clients experience a limited loss of impact, while b -type clients experience an extreme loss of impact from mismatches).

For instance, in the case of Daya, the loss of impact arises when clients who need legal representation to overcome financial abuse incorrectly seek and receive temporary housing. As another example, consider First Step, an organization that provides sustainable income opportunities for homeless individuals. (See details about First Step in the appendix.) When their clients with mental health issues receive job placement services instead of assistance with claiming disability insurance, First Step's services will have limited impact.

Advisory Effort: In order to reduce the loss of impact from service mismatches, the

NPO can provide guidance to their clients on choosing the most appropriate services for their needs. This could be in the form of hiring and training employees to design and conduct extended in-take interviews and professional tests of skills, improving intake processes and technology (e.g., software, web-resources), or administering health and behavioral examinations. Let $e_G \geq 0$ represent the level of the NPO's advisory effort. We denote by $\theta(e_G)$ the proportion of clients who would receive correct services when the NPO invests e_G in its advisory effort, where $\theta(e_G)$ is given by:

$$\theta(e_G) \doteq \underline{\theta} + \theta_o \cdot e_G. \quad (4.1)$$

The parameter $\theta_o > 0$ represents the rate at which a unit of advisory effort increases the likelihood of correct matches. The parameter $\underline{\theta} \geq 1/2$ denotes the likelihood that clients request appropriate services (best suited to their needs) when the NPO offers only a basic guideline about the services it offers (i.e., $e_G = 0$). The lower bound $1/2$ captures the fact that even without any advisory effort, in the worst-case scenario, the likelihood of mismatch is not worse than random chance. However, our general setting allows for $\underline{\theta}$ to also be larger than $1/2$ (i.e., $\underline{\theta} \in [1/2, 1)$), which captures situations where clients are thoroughly informed about their needs or the basic guideline provided by the NPO is effective. For instance, without investing any portion of resources (S), the NPO can provide some information on its website or mobile application (e.g., lists of services offered and frequently asked questions) to guide its clients on identifying the best-suited services. Without loss of generality, we focus our attention on combinations of parameters that ensure the probability function $\theta(e_G)$ lies in the unit interval.

Service Delivery Efforts: The NPO can increase its impact by investing more resources into the delivery of its services. We denote by $e_A \geq 0$ and $e_B \geq 0$ the NPO's efforts in providing the A - and B -type services, respectively. These efforts could be in the form of hiring and training employees for delivery of a particular type of service, contracting with

specialists (e.g., lawyers and tutors), or investing in infrastructure for service delivery (e.g., shelters and temporary housing). We model the impact generated by the NPO when it exerts e_j towards the j -type service, $j \in \{A, B\}$, and delivers it to the i -type clients, $i \in \{a, b\}$, as follows

$$I_{ij} \doteq \alpha_{ij} I_i \cdot (e_j)^\beta. \quad (4.2)$$

The parameter $\beta \in (0, 1]$ captures returns to scale of the NPO's service delivery efforts. We refer to β as the *scalability* level of the NPO's services. When $\beta = 1$, the impact generated by the NPO rises at a constant rate with any increase in service delivery efforts. However, when $\beta < 1$, the marginal impact created by the NPO decreases with an increase in service delivery efforts.

The scalability of the NPO's services may be limited by several practical constraints (Bradach 2003, Forti and Andrew 2014). The NPO transforms effort into impact by connecting clients to several sources, such as partners, governments, and volunteers (Wong 2015). Thus, any bottleneck in accessing these sources could limit the scalability of the NPO's services (Hurst 2012). For instance, in the case of Daya, legal services are provided to clients through a combination of in-house administrative work and pro-bono legal experts. While Daya can increase in-house staffing by spending more resources, it gets progressively more difficult for Daya to enhance legal expertise. The scale parameter β captures these types of limitations. In Subsection 4.5.2, we extend our analysis to the case where one of the NPO's services is more scalable than the other one.²

Service Design Problem: The NPO aims to maximize the total expected social impact generated through its activities. For a given level of advisory effort (e_G), the proportion of a -type clients that receive the B -type service is $(1 - \theta(e_G))p$, and the proportion of b -type clients that receive the A -type service is $(1 - \theta(e_G))(1 - p)$. Accordingly, we obtain the total

²We focus on the lack of scalability in service delivery efforts as they are more dependent on external sources (e.g., partners and government institutions). However, in some situations, the NPO's advisory effort may also suffer from lack of scalability, which can be captured by adding a power parameter to function $\theta(e_G)$ in equation (4.1). In that situation, the overall insights continue to hold, but at the expense of a more complicated exposition.

expected impact (TEI) that the NPO delivers as follows:

$$TEI(e_G, e_A, e_B) \doteq p\theta(e_G) \left(kI \cdot (e_A)^\beta \right) + p(1 - \theta(e_G)) \left(\alpha kI \cdot (e_B)^\beta \right) + (1 - p)\theta(e_G) \left(I \cdot (e_B)^\beta \right) + (1 - \theta(e_G)) (1 - p) \left(\alpha I \cdot (e_A)^\beta \right). \quad (4.3)$$

To simplify the exposition, we drop the subscript by denoting $I_b = I$ and $I_a = kI$. The first and third terms in equation (4.3) correspond to the NPO's impact for serving clients who receive the best-suited service for their needs. The second and fourth terms in equation (4.3) correspond to the NPO's reduced impact for the two cases of mismatch (accordingly, these terms contain α).

The NPO chooses the optimal investments for its advisory effort (e_G^*) and service delivery efforts (e_A^*, e_B^*) to maximize its total expected impact using its limited resources (S). The NPO's optimization problem is given by:

$$\begin{aligned} \max_{\{e_G, e_A, e_B\}} \quad & TEI(e_G, e_A, e_B) \\ \text{s.t.}, \quad & e_G + e_A + e_B \leq S, \end{aligned} \quad (4.4)$$

$$e_G \geq 0, e_A \geq 0, e_B \geq 0. \quad (4.5)$$

The optimization problem outlined above highlights the inter-dependence between advisory and service delivery efforts. While increasing advisory effort increases the likelihood of clients receiving the appropriate services, it comes at the cost of limiting the NPO's service delivery efforts. Note that advisory and service delivery efforts are complementary in the objective function (4.3), but they are drawn from the same pool of resources, as in constraint (4.4).³ In practice, NPOs may receive earmarked donations that can be used only for

³In practice, advisory and service delivery efforts may vary in terms of the financial resources they consume; that is, efforts may hold different coefficients in constraint (4.4) (e.g., $ae_G + be_A + ce_B \leq S$). However, by change of variables, one can show that the effect of such asymmetries can be captured by parameters k and θ_o . That is, defining $\bar{e}_G = ae_G$, $\bar{e}_A = be_A$, and $\bar{e}_B = ce_B$, we can map $\bar{\theta}_o = \theta_o/a$ and $\bar{k} = (c/b)^\beta \cdot k$. Thus, this model generates similar insights but at the expense of a more complicated exposition, given the presence of additional parameters (a, b, c).

a specific type of service delivery effort. In Subsection 4.5.1, we extend our model to include earmarked funding.

4.4 Results

We characterize the NPO's optimal service design, and generate insights on how it depends on the characteristics of the its clients' needs and services it provides. In particular, we analyze the service design of NPOs with scalable services in §4.4.1 and with non-scalable services in §4.4.2.

4.4.1 Service Design of an NPO with Scalable Services

In this subsection, we first analyze the service design of an NPO that offers scalable services (i.e., $\beta = 1$), which is determined by optimal choices of advisory and service delivery efforts (e_G^*, e_A^*, e_B^*). We then study the effect of the client mix (p), impact factor (k), and loss of impact from mismatches (α) on the NPO's optimal service design.

Proposition 4. SERVICE DESIGN OF SCALABLE NPO: *When $\beta = 1$, at least one of the optimal efforts (e_G^*, e_A^*, e_B^*) is equal to zero. That is,*

- (i) *there exists a threshold $\hat{S} > 0$, such that $e_G^* > 0$ if $S > \hat{S}$ and $e_G^* = 0$ otherwise, and*
- (ii) *there exists a threshold p_o , such that $e_A^* > 0$ and $e_B^* = 0$ if $p > p_o$ and $e_A^* = 0$ and $e_B^* > 0$ if $p \leq p_o$.*

Specifically, for $S > \hat{S}$, $(e_G^, e_A^*, e_B^*) = \left\{ \left(\frac{S-\hat{S}}{2}, \frac{S+\hat{S}}{2}, 0 \right) \text{ if } p > p_o \text{ and } \left(\frac{S-\hat{S}}{2}, 0, \frac{S+\hat{S}}{2} \right) \text{ otherwise} \right\}$, and for $S \leq \hat{S}$, $(e_G^*, e_A^*, e_B^*) = \{(0, S, 0) \text{ if } p > p_o \text{ and } (0, 0, S) \text{ otherwise}\}$, where $p_o \doteq \frac{1}{k+1}$ and*

$$\hat{S} \doteq \frac{\theta}{\theta_o} \left(\frac{\max\{pk, 1-p\} + \alpha \cdot \min\{pk, 1-p\} \left(\frac{1-\theta}{\theta} \right)}{\max\{pk, 1-p\} - \alpha \cdot \min\{pk, 1-p\}} \right). \quad (4.6)$$

Proposition 4 (i) shows that when the NPO is severely resource-constrained (i.e., $S \leq \hat{S}$), it should channel resources toward only its service delivery efforts; otherwise, it should spread its resources between advisory and service delivery efforts to maximize its social impact.

Note that in the absence of a resource constraint, the total expected impact in equation (4.3) increases in all three types of efforts. However, when resource-constrained, the NPO has to prioritize its investments. Indeed, as Proposition 4 (i) shows the NPO should prioritize its service delivery efforts over its advisory effort when it has limited resources. The reason is because, even without any advisory effort, the expected impact can get improved by increasing service delivery efforts; however, without any service delivery efforts, no impact can be generated. In contrast, when the NPO has a sufficient amount of resources (i.e., $S > \hat{S}$), investing a portion of that toward the advisory effort can be effective in reducing the chances of mismatch, and thus generating a higher social impact. Figure 4.1 illustrates these results.

Moreover, Proposition 4 (ii) shows that when services are scalable, it is optimal for the NPO to specialize in only one type of service delivery. This implies that the NPO should not attempt to provide “everything for everyone;” instead, they should determine the type of a service to offer based on the impact factor (k) and the client mix (p). In particular, the NPO should invest only in the A -type service if $p > p_o$ (i.e., $pk > 1 - p$), and only in the B -type service otherwise. In other words, the NPO should focus on the service type that generates the greatest overall impact. This approach can be seen in action at NPOs such as Georgia Works, which could offer both disability insurance and employment services to the homeless individuals. However, given the scalability of their services and the relatively higher social impact of finding employment for clients, Georgia Works has chosen to only offer employment services, but not disability assistance.⁴

In Corollary 1, we study the effect of situational factors, such as the loss of impact due to mismatches (α), the mix of client types (captured by p), and the relative impact factor (k) on the threshold \hat{S} (which determines whether or not the NPO should investment in advisory effort).

Corollary 1. SENSITIVITY OF \hat{S} : *The threshold \hat{S} , defined in Proposition 4, is impacted by*

⁴Georgia Works communicates this focus directly to prospective clients in all forms of communication, including their website <http://www.georgiaworks.net/about-1>.

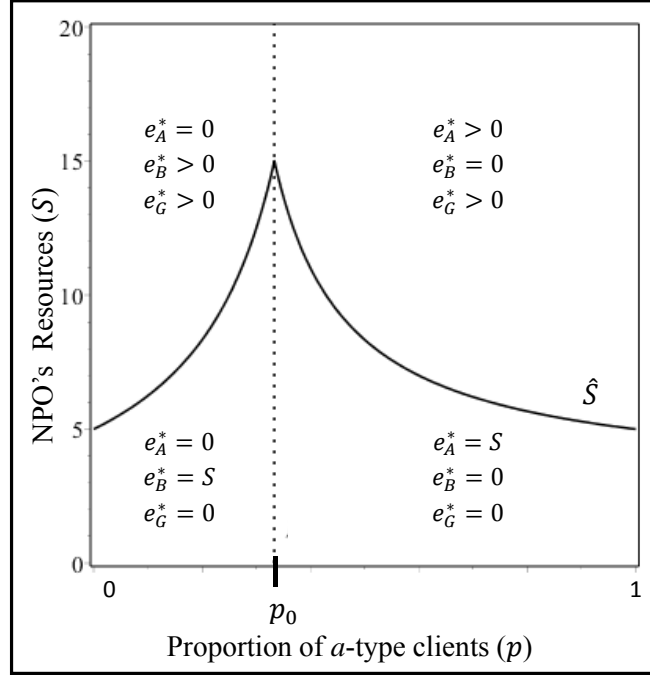


Figure 4.1: NPO's Optimal Service Design when $\beta = 1$

Note: Parameters: $k = 2$; $\underline{\theta} = 0.5$; $\theta_o = 0.1$; $\alpha = 0.5$. Note that $p_o = 1/3$.

situational factors as follows:

- (i) \hat{S} is increasing in α ,
- (ii) \hat{S} is increasing in p if and only if $p \leq p_o$, and
- (iii) \hat{S} is decreasing in k when $p > p_o$ (i.e., $p > 1/2$ or $k > 1/p - 1$); otherwise it is increasing in k .

Naturally, when the loss of impact from mismatches is low (i.e., α is large), there is less need for the NPO to exert advisory effort. Therefore, as shown in Corollary 1 (i), the threshold above which the NPO should invest in advisory effort is higher when α is large. In Corollary 2, we study the effect of α on the NPO's optimal efforts.

However, as shown in Figure 4.1, the NPO's advisory effort also depends on the client mix (p). Indeed, Corollary 1 (ii) shows that the threshold \hat{S} is non-monotonic with respect to p . Contrary to expectation, the NPO should be more willing to invest in advisory efforts when its clientele is dominated by one type (i.e., p closer to 0 or 1). To understand this, note that the NPO's clientele is more homogeneous when p is extreme. As a result, the lack

of guidance for clients can lead to a higher rate of mismatches. At the same time, because the NPO offers only a single service, these mismatches are more consequential because they lead to zero social impact. Therefore, when clients are more homogeneous, investments in advisory effort become necessary at an even lower level of available resources.

Inspecting the threshold \hat{S} further, Corollary 1 (iii) shows that \hat{S} may increase or decrease in the impact factor (k), depending on the type of service the NPO offers. Specifically, \hat{S} is decreasing in k when it is optimal to provide only A -type service (i.e., when $p > 1/2$ or $k > 1/p - 1$), and it is increasing in k otherwise.⁵ Figure 4.2 illustrates these results.

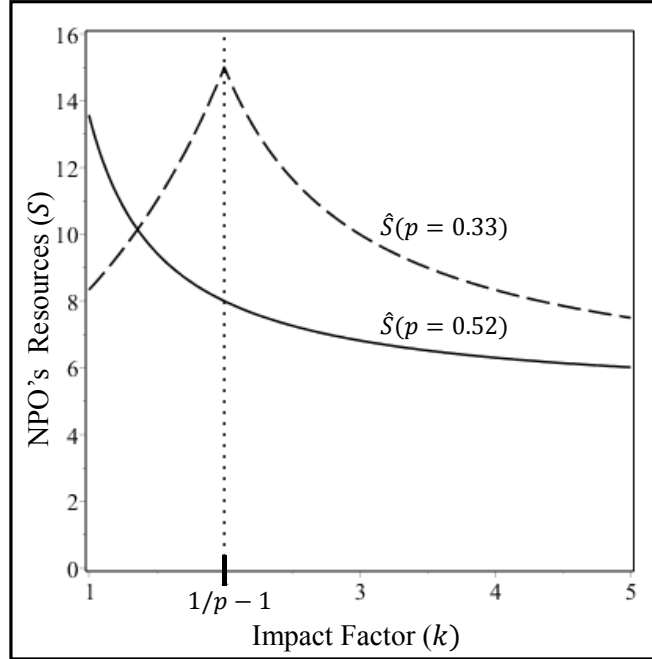


Figure 4.2: Effect of Impact Factor (k) on Threshold \hat{S}

Note: Parameters are the same as in Figure 4.1 with $p = 0.33$ and $p = 0.52$.

When k is very high, the impact generated from providing A -type service is significantly higher, and thus preventing the loss of impact from mismatches of a -type clients is important. Therefore, as shown in Figure 4.2, providing advisory effort is valuable at a lower level of resources (S) when k is higher. However, when the NPO offers only B -type service (i.e., when $p \leq 1/2$ and $k \leq 1/p - 1$), as k increases, it is better for the NPO to preserve its

⁵Note that, when the majority of the clientele belongs to the a -type ($p > 1/2$), the NPO provides only the A -type service regardless of k , i.e., $p > p_o$ holds for any $k \geq 1$.

resources for actual service delivery. Here, as k increases (from 1 to $1/p - 1$), the NPO may still create significant social impact by providing a -type clients with B -type service, despite the mismatches (naturally, this occurs only if α is sufficiently high). Therefore, providing advisory effort is valuable at a higher level of resources (S).

The loss of impact from mismatches plays an important role in determining the optimal level of advisory and service delivery efforts. In the next corollary, we study the sensitivity of the NPO's optimal service design with respect to the degree of loss of impact (α).

Corollary 2. EFFECT OF LOSS OF IMPACT α : *Consider (e_G^*, e_A^*, e_B^*) characterized in Proposition 4. Then, $e_A^* + e_B^* \geq e_G^*$ for all $\alpha \in [0, 1]$. In addition, there exists a threshold $\bar{\alpha}$ such that*

- (i) $e_G^* > 0$ and is decreasing in α for $\alpha \leq \bar{\alpha}$, and $e_G^* = 0$ for $\alpha > \bar{\alpha}$.
- (ii) e_A^* (or e_B^*) is increasing in α for $\alpha \leq \bar{\alpha}$, and it is equal to S for $\alpha > \bar{\alpha}$.

Corollary 2 shows that when the loss of impact from mismatches is lower (i.e., $\alpha > \bar{\alpha}$), the NPO should make no investments in advisory effort, and all resources should be used for delivery of services (in the form of e_A or e_B as given by Proposition 4 (ii)). In that case, even though mismatches can occur, the impact created by the NPO is significant, given the magnitude of resources invested in service delivery. However, when α is low (i.e., $\alpha \leq \bar{\alpha}$), mismatches result in significant loss of impact, thus providing guidance to clients is required to lower the probability of such loss. Figure 4.3 illustrates these results.

As shown in Figure 4.3, the difference between optimal service delivery and advisory efforts gets larger as α increases (with decreasing e_G^* and increasing e_A^*). Moreover, Corollary 2 and Figure 4.3 show that the NPO that offers scalable services should always invest more resources in its service delivery efforts than its advisory effort, i.e., $e_A^* + e_B^* \geq e_G^*$. Remarkably, this is true even when the impact loss due to mismatches is extreme (i.e., $\alpha = 0$). This, however, may not be the case if the NPO's services are not scalable, which we study in the next section.

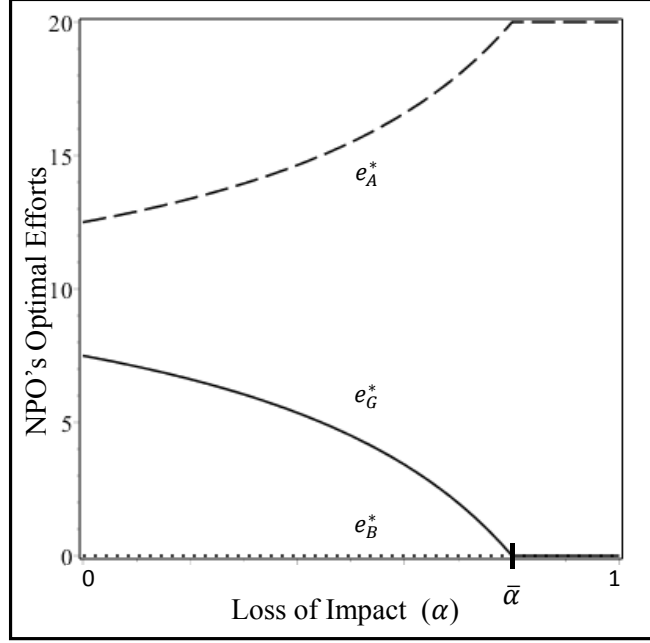


Figure 4.3: Effect of Loss of Impact Factor (α) on the NPO's Optimal Efforts when $\beta = 1$
Note: Parameters are the same as in Figure 4.1 with $p = 0.4$ and $S = 20$. Note that $p > p_0 = 1/3$.

4.4.2 Service Design of an NPO with Non-Scalable Services

In this subsection, we analyze the service design of an NPO that provides non-scalable services (i.e., $\beta < 1$). We first characterize the NPO's optimal service design for the case where the loss of impact from mismatches is severe (i.e., $\alpha = 0$), which also represents situations where the needs of different client types are disparate. This assumption helps the exposition and allows us to isolate the effect of the scalability factor β on the choices of advisory and service delivery efforts. We then discuss the results for situations where the loss of impact from mismatches is less severe (i.e., $\alpha > 0$).

Proposition 5. SERVICE DESIGN OF NON-SCALABLE NPO: *When $\beta < 1$ and $\alpha = 0$, it is optimal for the NPO to invest in both types of service delivery efforts $(e_A^*, e_B^*) > 0$. In addition,*

(i) *there exists a threshold $\tilde{S} > 0$, such that $e_G^* > 0$ if and only if $S > \tilde{S}$, and*

(ii) *there exists a threshold p_o , such that $e_A^* > e_B^*$ if and only if $p > p_o$.*

Specifically, for $S \leq \tilde{S}$: $(e_G^, e_A^*, e_B^*) = (0, S(pk)^{\frac{1}{1-\beta}} \varphi(p, k, \beta), S(1-p)^{\frac{1}{1-\beta}} \varphi(p, k, \beta))$, and*

for $S > \tilde{S}$:

$$(e_G^*, e_A^*, e_B^*) = \left(\left(\frac{1}{1+\beta} \right) (S - \tilde{S}), \left(S + \frac{\theta}{\theta_o} \right) (pk)^{\frac{1}{1-\beta}} \nu(p, k, \beta), \left(S + \frac{\theta}{\theta_o} \right) (1-p)^{\frac{1}{1-\beta}} \nu(p, k, \beta) \right),$$

where $\tilde{S} \doteq \frac{\beta \theta}{\theta_o}$, p_o is as defined in Proposition 4, and

$$\varphi(p, k, \beta) \doteq \left((p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}} \right)^{-1}, \quad \nu(p, k, \beta) \doteq \left(\frac{\beta}{1+\beta} \right) \varphi(p, k, \beta).$$

Proposition 5 shows that when the NPO's services are not scalable (i.e., $\beta < 1$), the NPO can generate higher social impact if it balances its investments toward both types of services (i.e., $e_A^* > 0$ and $e_B^* > 0$), as opposed to investing all resources in only one type of service. In addition, Proposition 5 (i) shows that, similar to a scalable NPO (Proposition 4 (i)), the non-scalable NPO should also invest in advisory effort only when it has sufficient amount of resources. In addition, this threshold is smaller when the degree of scalability (β) is lower. Naturally, the lack of scalability imposes a limit on the impact that the NPO can generate by its service delivery efforts. In such a scenario, the NPO can obtain a greater impact by increasing its advisory effort (which reduces mismatches), than through its service delivery efforts (which have decreasing marginal returns to scale).

Unlike the resource threshold of a scalable NPO (\hat{S}), which depends on the client mix (p) and impact factor (k) (Corollary 1), the resource threshold of a non-scalable NPO (\tilde{S}) is independent of these factors (when the loss of impact is severe). Recall that the scalable NPO provides only a single type of service (Proposition 4), which makes it critical to judiciously provide its advisory effort so not to turn down its high-priority clients (who receive the greater overall impact). Therefore, the resource threshold and level of advisory effort of the scalable NPO are both influenced by p and k . However, the non-scalable NPO that offers both types of services would adjust its service delivery efforts by taking into account its client mix and their relative impact. In particular, Proposition 5 (ii) shows that, regardless of whether the non-scalable NPO invests in advisory effort or not, the optimal balancing

ratio of its service delivery efforts is as follows:

$$\frac{e_A^*}{e_B^*} = \left(\frac{pk}{1-p} \right)^{\frac{1}{1-\beta}}. \quad (4.7)$$

This optimal balancing ratio depends on the client mix (p) and the impact factor (k), and most importantly, the degree of scalability of the NPO's services (β). The balance would be tilted towards the type of service that yields a greater overall impact; that is, the NPO should invest more in the A -type service than the B -type service when $pk > 1 - p$, and vice versa. This is consistent with the results in Proposition 4, except that a non-scalable NPO should provide both types of services, but with adjusted intensities. Since the balancing adjusts service delivery efforts based on the impact factor, the NPO's advisory effort depends only on the amount of resources and the scalability of its services.

Moreover, equation (4.7) shows that the optimal service delivery efforts are more balanced when services are less scalable (β is small); however, as services become more scalable (β increases), the ratio of efforts becomes more skewed and eventually the NPO offers only one type of service when $\beta \rightarrow 1$ (Proposition 4). In the next corollary, we study the sensitivity of the NPO's optimal service design with respect to the scalability factor β .

Corollary 3. EFFECT OF SCALABILITY FACTOR β : *Consider thresholds \tilde{S} and p_o and the optimal efforts (e_G^*, e_A^*, e_B^*) characterized in Proposition 5. There exists a threshold $\beta_o \doteq \frac{S\theta_o}{2\theta + S\theta_o}$, such that $e_G^* > e_A^* + e_B^*$ if and only if $\beta < \beta_o$. In addition,*

- (i) for $S > \tilde{S}$: e_G^* is decreasing in β ; e_A^* is increasing in β if $p > p_o$, and is unimodal in β otherwise; and e_B^* is unimodal in β if $p > p_o$, and increasing in β otherwise; and*
- (ii) for $S \leq \tilde{S}$: $e_G^* = 0$; e_A^* is increasing in β if and only if $p > p_o$; and e_B^* is decreasing in β if and only if $p > p_o$.*

Corollary 3 shows that when the scalability of services is lower than a threshold (β_o), the NPO should invest more in its advisory effort, and its advisory effort should even exceed its total service delivery effort. Figure 4.4 illustrates the NPO's optimal efforts with respect to

the scalability factor.

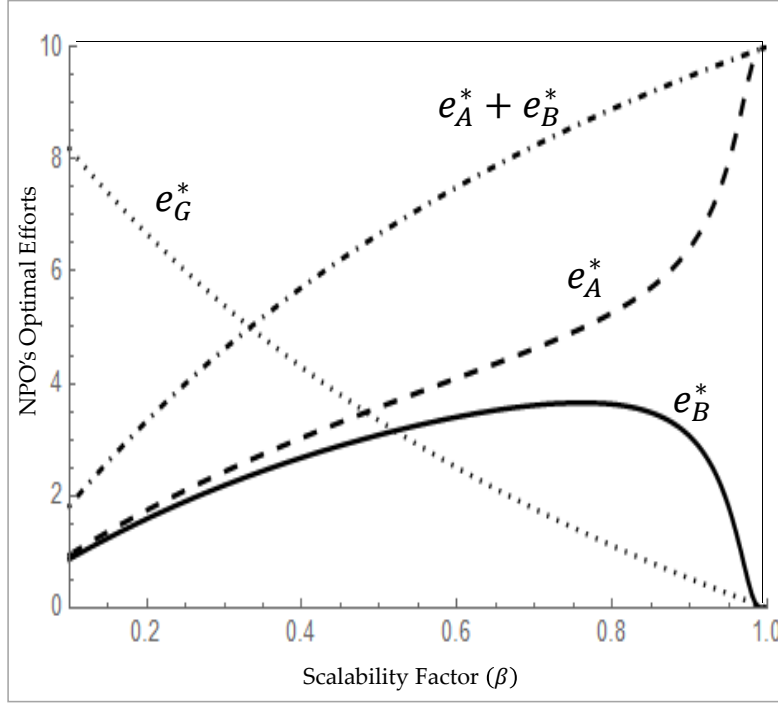


Figure 4.4: Effect of Scalability Factor (β) on the NPO's Optimal Efforts

Note: Parameters: $k = 2$, $\underline{\theta} = 0.5$, $\theta_o = 0.05$, $S = 10$, $p = 0.35$, and $\alpha = 0$. Note that $\beta_o = 1/3$.

The non-scalable NPO should invest more resources toward the service that has a higher overall impact, i.e., higher impact factor or higher proportion of clients in need (Proposition 5). In addition, Corollary 3 shows that as the scalability of the NPO's services increases (i.e., $\beta \rightarrow 1$), the NPO should reduce its delivery of the less impactful service (see Figure 4.4). This prioritization primarily arises due to the scarcity of the NPO's resources.

The main insights from Proposition 5 continue to hold even when the loss of impact from mismatches is less severe (i.e., $\alpha > 0$). Figure 4.5 illustrates the NPO's optimal service design for different values of loss of impact α . For each value of α , there exists a unique threshold beyond which it is optimal for the NPO to invest resources in advisory efforts. In addition, the NPO should invest more in delivering a service that either generates a relatively higher impact (e.g., k is large) or has a higher proportion of clients who are in need of that type of service (e.g., p is high).

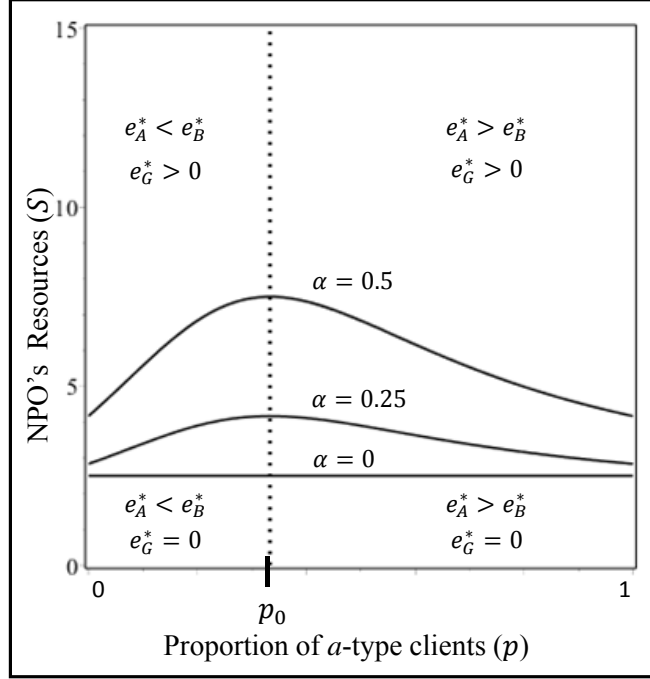


Figure 4.5: Optimal Service Design when $\beta < 1$ and for Different Degrees of Loss of Impact
Note: Parameters are the same as in Figure 4.1, except that $\beta = 0.5$ and $\alpha \in \{0, 0.25, 0.5\}$.

4.5 Extensions

In this section, we extend our model and analysis in several dimensions. In particular, in §4.5.1, we study the effect of earmarked funding on the NPO's optimal service design; in §4.5.2, we study the service design of an NPO that offers services with different levels of scalability; and in §4.5.3, we study the service design of an NPO that offers services with different degrees of loss of impact.

4.5.1 The Effect of Earmarked Funds

Donors often direct their gifts to specific causes, and constrain NPOs to use their donations to earmarked services (Stauffer et al. 2016, Kessler et al. 2017). For instance, First Step may receive funds that can only be used toward job placement services for homeless individuals, but not for providing them assistance with disability insurance services.

In this section, we extend our model of the NPO's service design to include earmarked

funds. Without loss of generality, we consider the case where the NPO receives $\xi_B > 0$ additional earmarked funds to invest exclusively in its B -type service delivery effort. The NPO's service design problem in Section 4.3 can then be modified as follows:

$$\begin{aligned} \max_{\{e_G, e_A, e_B\}} \quad & TEI(e_G, e_A, e_B) \\ \text{s.t.}, \quad & e_G + e_A + e_B \leq S + \xi_B, \end{aligned} \tag{4.8}$$

$$e_G + e_A \leq S, \tag{4.9}$$

$$e_G \geq 0, e_A \geq 0, e_B \geq 0,$$

where $TEI(e_G, e_A, e_B)$ is as given by equation (4.3). The additional constraint (4.9) implies that the earmarked funds cannot be invested in advisory effort and A -type service delivery. In Proposition 6, we characterize the NPO's optimal service design with earmarked funds and in situations where the loss of impact from mismatches is severe. Similar insights continue to hold in situations where the loss of impact is less severe, but we focus on this case to simplify the exposition.

Proposition 6. *When $\beta < 1$, $\alpha = 0$, and $\xi_B > 0$, it is optimal for the NPO to invest in both types of service delivery efforts $(e_A^*, e_B^*) > 0$. In addition,*

(i) there exists a threshold $\tilde{\tilde{S}} > 0$, such that $e_G^ > 0$ if and only if $S + \xi_B > \tilde{\tilde{S}}$. Further, $\tilde{\tilde{S}} \leq \tilde{S}$ where \tilde{S} is as defined in Proposition 5; and*

(ii) there exists a threshold $\tilde{\xi}_B(S) > 0$, such that $e_B^ > \xi_B$ if $\xi_B < \tilde{\xi}_B(S)$ and $e_B^* = \xi_B$ otherwise. Further, threshold $\tilde{\xi}_B(S)$ increases in S .*

Proposition 6 (i) shows that with earmarked funds, it is more critical for the NPO to provide advisory effort to its clients, as compared to situations with no earmarked funds. In particular, comparing Proposition 5 (i) and Proposition 6 (i), the resource threshold above which the NPO should invest in advisory effort is smaller when the NPO has additional earmarked funds ($\tilde{\tilde{S}} \leq \tilde{S}$). Moreover, Figure 4.6 shows that the optimal advisory effort increases as the earmarked funds get larger.

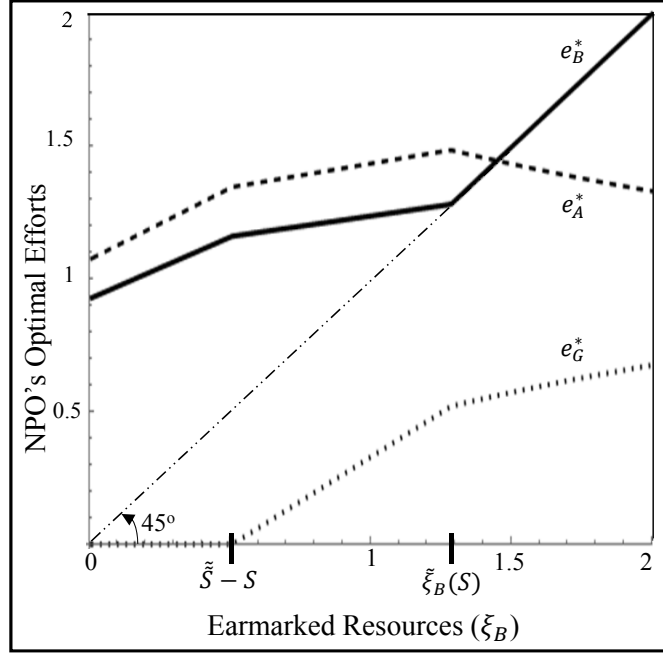


Figure 4.6: Effect of the Earmarked Funds on the NPO's Optimal Efforts

Note: Parameters are the same as in Figure 4.5 with $S = 2$, and $p = 0.35$. Note that $p > p_o = \frac{1}{3}$.

In addition, Proposition 6 (ii) shows that when the amount of earmarked funds is sufficiently high ($\xi_B \geq \tilde{\xi}_B$), it is optimal for the NPO to invest in the B -type service delivery effort only at the level of the earmarked funds, and nothing more. Naturally, large earmarked funds force the NPO to invest more resources in the B -type service delivery effort, which can be higher than what the NPO would have optimally invested if there were no earmarked funds (see Figure 4.6).

In general, although the ξ_B is earmarked, the infusion of additional funds allows the NPO to offer more advisory and service delivery efforts. However, there is a notable exception: even if the A -type service has a higher overall impact (i.e., $p > p_o$), the NPO's optimal effort of A -type service may decrease as the earmarked funds increase. For example, given the parameters in Figure 4.6, the NPO would maximize its impact by investing more in the A -type service if there were no earmarked funds (i.e., $p > p_o$). However, the large earmarked funds for the B -type service creates a situation in which mismatches of b -type clients to the A -type service lead to a heavy loss of impact (when α is small). As a result, the NPO should

divert more of its resources to its advisory effort, even though it implies a reduction in its A -type service delivery effort. This result shows that although earmarked funding is better than no funding at all, it may have unintended consequences for clients. Earmarked funds for one type of service can lead to an increase in investment of resources toward advisory effort, but crowd out the investment of the NPO's resources in providing the non-earmarked service (even if the other service generates higher impact).

4.5.2 Asymmetry in Scalability of Services

In practice, the NPO's services may vary in terms of their scalability. For instance, an NPO that serves survivors of domestic violence may offer scalable counseling services, but non-scalable legal services. In this subsection, we study how the asymmetry in the scalability of the NPO's services can impact its optimal service design. We denote by β_A and β_B the degree of scalability of A -type and B -type services, respectively. Accordingly, the the total expected impact (TEI) in equation (4.3) can be modified as follows:

$$TEI(e_G, e_A, e_B) = p\theta(e_G) \left(kI \cdot (e_A)^{\beta_A} \right) + p(1 - \theta(e_G)) \left(\alpha kI \cdot (e_B)^{\beta_B} \right) + \quad (4.10)$$

$$(1 - p)\theta(e_G) \left(I \cdot (e_B)^{\beta_B} \right) + (1 - p)(1 - \theta(e_G)) \left(\alpha I \cdot (e_A)^{\beta_A} \right).$$

Proposition 7 characterizes the NPO's optimal service design for the case where the A -type service is less scalable than the B -type service and the loss of impact from mismatches is severe (i.e., $\alpha = 0$). Similar insights continue to hold in situations where the loss of impact is less severe, but we focus on this case to simplify the exposition.

Proposition 7. *When $\beta_A \leq \beta_B < 1$ and $\alpha = 0$, there exists a threshold $S_G > 0$, such that $e_G^* > 0$ if and only if $S > S_G$. Specifically,*

- (i) *for $S \leq S_G$, $(e_G^*, e_A^*, e_B^*) = (0, S - e_B^*, e_B^*)$, where e_B^* is the unique solution to $e_B + e_B^{1-\beta_B} \bar{\nu}(p, k, \beta_A, \beta_B) = S$ with $\bar{\nu}(p, k, \beta_A, \beta_B) \doteq \left(\frac{\beta_A k p}{\beta_B(1-p)} \right)^{\frac{1}{1-\beta_A}}$; and*
- (ii) *for $S > S_G$, $(e_G^*, e_A^*, e_B^*) = \left(S - (e_B^*)^{\frac{1-\beta_B}{1-\beta_A}} \bar{\nu}(p, k, \beta_A, \beta_B) - e_B^*, (e_B^*)^{\frac{1-\beta_B}{1-\beta_A}} \bar{\nu}(p, k, \beta_A, \beta_B), e_B^* \right)$,*

where e_B^* is the unique solution to $f(e_B) = 0$ with

$$\begin{aligned} f(e_B) \doteq & e_B^{\frac{\beta_A(1-\beta_B)}{1-\beta_A}} \underline{\theta} \left((1-p) \beta_B \bar{\nu}(p, k, \beta_A, \beta_B) + pk \bar{\nu}(p, k, \beta_A, \beta_B)^{\beta_A} \right) \\ & + e_B^{\beta_B} (\beta_B + 1) (1-p) \underline{\theta} - e_B^{\beta_B-1} \beta_B (1-p) (S\underline{\theta} + \theta_o). \end{aligned} \quad (4.11)$$

Figure 4.7 illustrates the NPO's optimal efforts with respect to the scalability of A -type service (β_A) when the scalability of B -type service is fixed at 0.4. As the scalability of A -type service increases, it becomes optimal for the NPO to increase its investment in the service delivery of A -type and to decrease its investment in the service delivery of B -type. In addition, beyond a certain threshold, even though $\beta_A \leq \beta_B$, the NPO should invest more resources in the A -type service delivery than in the B -type service delivery. The reason is because the overall impact of A -type service is more than B -type service (i.e., $pk > 1 - p$). Thus, consistent with our results in Proposition 5, the NPO should invest more in the service that has a higher overall impact.

Moreover, Figure 4.7 shows that as the scalability of A -type service increases, the NPO should decrease its advisory effort and increase its total service delivery efforts. This shows that the insights from Corollary 3 continue to hold even in situations where the NPO's services have different scalability levels.

4.5.3 Asymmetry in Loss of Impact from Mismatches

In practice, the loss of impact due to mismatches may vary for different client types and services. For instance, in the case of First Step, the loss of impact is significant when clients with mental health issues seek and receive job placement services, but it is less severe when clients who are eligible for employment receive help with claiming disability insurance. In this subsection, we study how the asymmetry in the loss of impact can influence the NPO's optimal service design. Considering α_{aB} and α_{bA} , the total expected impact (TEI)

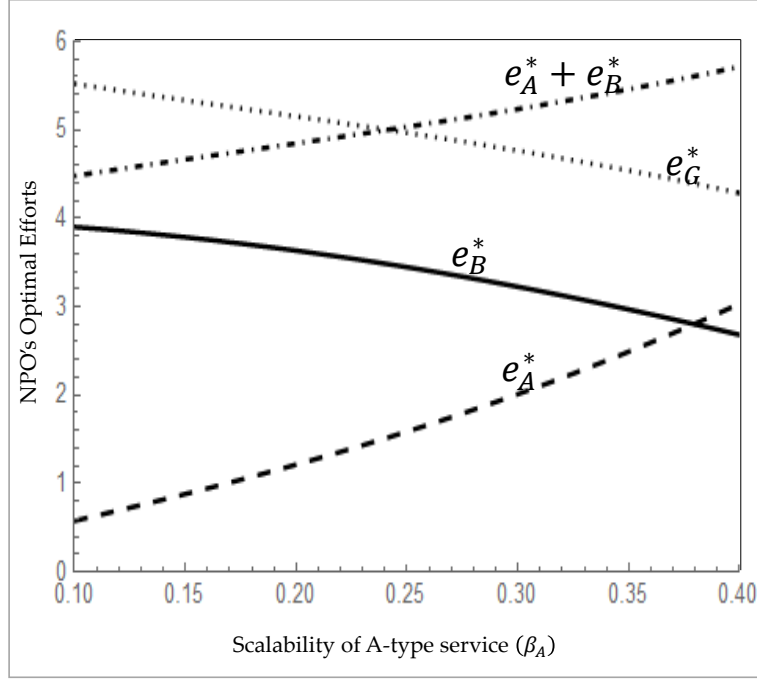


Figure 4.7: NPO's Optimal Efforts with Respect to β_A

Note: Parameters are the same as in Figure 4.4 with $\beta_B = 0.4$ and $\beta_A \in [0.05, \beta_B]$.

in equation (4.3) can be modified as follows:

$$TEI(e_G, e_A, e_B) = p\theta(e_G) \left(kI \cdot (e_A)^\beta \right) + p(1 - \theta(e_G)) \left(\alpha_{aB} kI \cdot (e_B)^\beta \right) + \quad (4.12)$$

$$(1 - p)\theta(e_G) \left(I \cdot (e_B)^\beta \right) + (1 - p)(1 - \theta(e_G)) \left(\alpha_{bA} I \cdot (e_A)^\beta \right).$$

Proposition 8 characterizes the NPO's optimal service design for the case where the loss of impact from b -type clients receiving A -type service is severe (i.e., $\alpha_{bA} = 0$), but the loss of impact from a -type clients receiving B -type service is less severe (i.e., $\alpha_{aB} = \alpha \in (0, 1)$). In addition, we focus on situations where the NPO's services are scalable to simplify the exposition.

Proposition 8. *When $\alpha_{bA} = 0$, $\alpha_{aB} = \alpha \in (0, 1)$, and $\beta = 1$,*

(i) there exists a threshold $\hat{S}_G(\alpha) > 0$, such that $e_G^ > 0$ if $S > \hat{S}_G(\alpha)$ and $e_G^* = 0$ otherwise.*

Also,

(ii) there exists a threshold $\bar{p}(\alpha)$, such that $e_A^ > 0$ and $e_B^* = 0$ if $p > \bar{p}(\alpha)$ and $e_A^* = 0$ and*

$e_B^* > 0$ if $p \leq \bar{p}(\alpha)$.

Further, $\hat{S}_G(\alpha)$ is non-decreasing in α , $\bar{p}(\alpha)$ is increasing in α and $\bar{p}(\alpha) > p_o$, where p_o is as defined in Proposition 4.

Proposition 8 shows that, similar to Proposition 4, it is optimal for the NPO to specialize in only one type of service delivery. However, given the asymmetry in loss of impact, the NPO should determine the type of service to offer not only by considering the impact factor (k) and the client mix (p), but also the loss of impact of a -type clients (α). Specifically, the threshold $\bar{p}(\alpha)$ below which the NPO should invest in its B -type service increases as the loss of impact of a -type clients decreases (i.e., α increases). In addition, the threshold $\hat{S}_G(\alpha)$ above which the NPO should invest in its advisory effort increases as the loss of impact of a -type clients decreases (i.e., α increases).

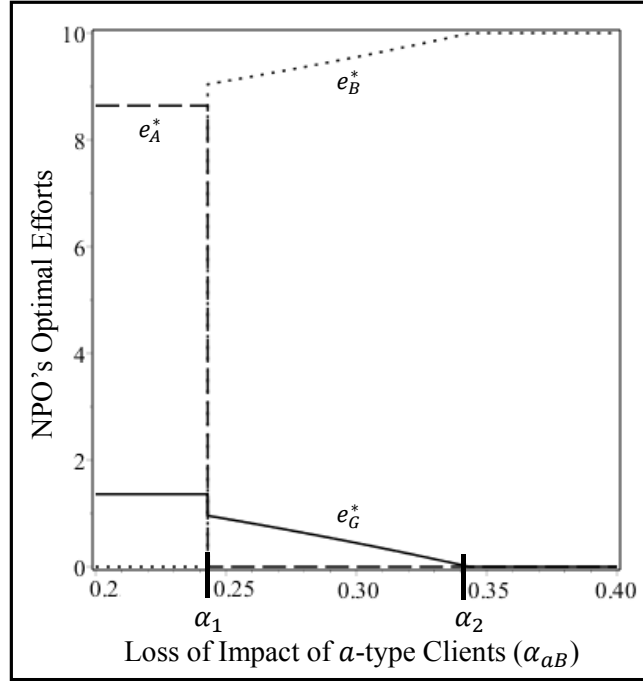


Figure 4.8: NPO's Optimal Efforts with Respect to α_{aB}

Note: Parameters are the same as in Figure 4.1, with $p = 0.34$, $\alpha_{bA} = 0.2$, $S = 10$, and $\alpha_{aB} \in [\alpha_{bA}, 0.4]$. Note that $\alpha_1 = \{\alpha \mid \bar{p}(\alpha) = p\}$ and $\alpha_2 = \{\alpha \mid \hat{S}_G(\alpha) = S\}$.

Figure 4.8 illustrates the NPO's optimal efforts with respect to the loss of impact of a -type clients (α) when the loss of impact of b -type clients is constant and equal to 0.2. It can

be seen that for large α , the NPO should invest all of its resources in the delivery of B -type service (i.e., when $\alpha \geq \alpha_2$, which implies $\hat{S}_G(\alpha) > S$ and $\bar{p}(\alpha) \geq p$); for intermediate α , it should spread its resources between its advisory effort and B -type service delivery effort (i.e., when $\alpha_1 \leq \alpha < \alpha_2$, which implies $\hat{S}_G(\alpha) \leq S$ and $\bar{p}(\alpha) \geq p$); and finally, for small α , it should spread its resources between advisory effort and A -type service delivery effort (i.e., when $\alpha \leq \alpha_1$, which implies $\hat{S}_G(\alpha) \leq S$ and $\bar{p}(\alpha) < p$).

4.6 Discussion and Practical Illustration

In this section, we use numerical examples to illustrate how our results may apply in practice for an NPO's service design decisions. As discussed above, Daya provides services to survivors of domestic violence. In supporting these clients, Daya aims to minimize economic consequences of those occurrences, such as medical costs, employment, and housing attainment (Gerberding et al. 2003). Therefore, the direct costs incurred by survivors of a particular abuse offers a useful proxy for the impact achievable through Daya's activities.⁶

The two most common types of abuses experienced by Daya's clients are emotional abuse (e.g., control over financial resources, employment, excommunication from friends and family), and physical abuse (e.g., battery, assault, and sexual crimes). The frequency of emotional abuse is roughly 1.5 times that of physical abuse, and together they account for a significant majority of all abuses suffered by Daya's clients. This is consistent with other studies, which report that number of women emotionally abused by their spouses to those physically abused by spouses to be around 1.41 (Young et al. 1997). Accordingly, we consider $p = 0.6$. As emotional abuse is a persistent issue with long-term implications for workplace preparation and engagement, lost wages and lost housework from emotional abuse tend to be significantly higher than from physical abuse (Chen 2017). The ratio of monetary costs from emotional abuse to the monetary costs from physical abuse has been estimated to be

⁶Although the emotional aspects of abuse may be more significant than the quantifiable economic implications, two points must be noted: first, non-pecuniary factors are heterogeneous and harder to quantify; second, NPOs are motivated to quantify the economic impact of their work for donors and funding agencies, despite the obvious narrowness of this measure.

around four (McLean and Bocinski 2017). Recall from Propositions 4 and 5 that the ratio of the costs, which is equivalent to the impact factor k , is sufficient to determine the NPO’s optimal service design (in other words, the actual values of the costs are not needed).

Partly due to their predicament and partly due to the lack of prior exposure to organizations like Daya, clients are often unable to select suitable services without guidance from Daya’s counselors. Based on this, we assume that $\underline{\theta} = 0.5$. Further, Daya estimates that eight full-time counselors will be required to provide a sufficiently deep intake to all of its clients for mismatches to be eliminated. As the average salary of a case manager in Houston, TX is around \$50,000 per year,⁷ we assume that the returns to advisory effort is $\theta_0 = 1.25 \times 10^{-6}$ ($= 0.5/400,000$). For simplicity, we consider the case when Daya’s annual budget is \$400,000.

As a summary measure of the NPO’s design decisions, we consider the optimal fraction of the resources extended by the NPO in providing guidance to clients (i.e., advisory effort to the total service delivery efforts). Table 4.1 shows how this fraction of advisory effort varies with the scalability of the NPO’s services (β) and the loss of impact due to mismatches (α). The table shows that advisory effort is most valuable when services are less scalable (low β) and the loss of impact due to mismatches is extreme (α close to 0). Indeed, it might be optimal for the NPO to focus on its advisory effort (coupled with a less amount of actual service delivery efforts) when its services are not scalable and very specific to clients’ needs, which is reflected by values larger than 1. On the other hand, when either its services are more scalable or the loss of impact is low, minimal guidance is sufficient.

As discussed in Subsection 4.5.1, NPOs often attract earmarked funds that are directed to particular services. In Table 4.2, we consider the impact of earmarking on the same case that was examined in Table 4.1. As earmarked funds increase, the optimal fraction of the NPO’s advisory effort to its total service delivery efforts decreases. This is driven primarily by the fact that the NPO has to direct the high amount of earmarked funds to its

⁷<https://www.indeed.com/salaries/Non-Profit-Salaries,-Houston-TX>.

Table 4.1: Optimal Ratio of Advisory Effort to Service Delivery Efforts

		Scalability of Services β									
Loss of Impact α		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	0	4.50	2.00	1.17	0.75	0.50	0.33	0.21	0.13	0.06	0.00
	0.1	4.02	1.78	1.03	0.66	0.44	0.30	0.19	0.11	0.04	0.00
	0.2	3.54	1.54	0.89	0.56	0.37	0.25	0.16	0.09	0.02	0.00
	0.3	3.04	1.30	0.72	0.44	0.28	0.18	0.11	0.06	0.00	0.00
	0.4	2.54	1.04	0.54	0.29	0.16	0.08	0.04	0.02	0.00	0.00
	0.5	2.03	0.75	0.32	0.09	0.00	0.00	0.00	0.00	0.00	0.00
	0.6	1.49	0.43	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.7	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.8	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Note: The numbers in cells correspond to $e_G^*/(e_A^* + e_B^*)$; Parameters: $S = 400,000$, $p = 0.6$, $k = 4$, $\theta_0 = 1.25 \times 10^{-6}$, $\underline{\theta} = 0.5$

service delivery. However, as the loss of impact decreases, the fraction of advisory effort may increase or decrease with α . When there is no earmarked funding, as shown in Table 4.1, the fraction of advisory effort decreases with α . However, when earmarked funding is sufficiently high, the fraction of advisory effort increases with α . This is because the earmarked service can benefit the other service when loss of impact is small (i.e., α is large). Therefore, in such situations, the NPO can invest less in its *A*-type service delivery effort and more in its advisory effort.

This illustration shows that in designing their services, NPOs should take into account the scalability of their services as well as the loss of impact from mismatches. Although obtaining exact estimates of these parameters may be difficult, NPOs can benchmark themselves with respect to peer organizations, and also observe directional trends in these situational factors. For instance, as an NPO gets more mature, it may become more efficient in delivering its services and build improved access to external resources (via expanding its network and building trust), which implies higher scalability. Similarly, the loss of impact from mismatches may decline over time as the NPO implements client management routines and recovery procedures. As essential parameters such as scalability and loss of impact evolve,

Table 4.2: Earmarked Funds and the Optimal Ratio of Advisory Effort to Service Delivery Efforts

		Earmarked Funds ξ_B (in 1000s)										
		0	20	40	60	80	100	120	140	160	180	200
Loss of Impact α	0	0.97	0.91	0.83	0.76	0.70	0.65	0.60	0.57	0.53	0.50	0.47
	0.1	0.94	0.91	0.83	0.77	0.71	0.66	0.62	0.58	0.55	0.52	0.49
	0.2	0.89	0.89	0.83	0.77	0.71	0.67	0.63	0.59	0.56	0.53	0.50
	0.3	0.84	0.84	0.83	0.77	0.71	0.67	0.63	0.59	0.56	0.53	0.50
	0.4	0.78	0.78	0.78	0.77	0.71	0.67	0.62	0.59	0.56	0.53	0.50
	0.5	0.73	0.73	0.73	0.73	0.71	0.67	0.63	0.59	0.56	0.53	0.50
	0.6	0.67	0.67	0.67	0.67	0.67	0.67	0.62	0.59	0.56	0.53	0.50
	0.7	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.59	0.56	0.53	0.50
	0.8	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.56	0.53	0.50
	0.9	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.53	0.50

Note: The numbers in cells correspond to $e_G^*/(e_A^* + e_B^*)$; Parameters: $S = 400,000$, $p = 0.6$, $k = 4$, $\theta_0 = 1.25 \times 10^{-6}$, $\underline{\theta} = 0.5$, $\beta = 0.5$.

our findings can help NPOs decide on how to invest their resources in various activities, such as hiring employees, expanding infrastructure, and training volunteers.

4.7 Conclusion

Non-profit organizations (NPOs) that support and serve distressed individuals are often the last resort for those who are marginalized in society. In order to maximize the social impact from their work and provide a transformative experience for their clients, NPOs provide different services that specifically cater to different client needs. Unfortunately, due to various reasons, clients may be unable to articulate their needs accurately. To reduce mismatches between client needs and services provided, NPOs can invest in advisory effort during the intake process. While indirectly beneficial for generating social impact, advisory efforts consume resources that NPOs could have spent in delivering impact-generating services.

In this paper, we address an important question raised by this trade-off: How should an NPO invest its limited resources between the advisory and service delivery activities? Motivated by our involvement with NPOs in several regions of the United States, we develop a model of a resource-constrained NPO that serves clients with diverse needs (in terms of

type and the intensity of their needs). Our model captures salient elements of these NPOs' operations, such as the limited scalability of their services and the loss of social impact due to clients-services mismatches. In this context, the NPO should optimally allocate its resources into advisory and service delivery activities to maximize its overall social impact.

Our analysis reveals several first-order insights for NPOs. First, we find that when the NPO is severely resource-constrained, it is optimal to offer only basic guidance to its clients; instead, all its resources should be directed toward service delivery activities. In contrast, when the NPO has sufficient amount of resources, it is optimal to spread resources between both advisory and service delivery activities. Second, although the NPO may have a tendency to provide several types of services to cater to different client types, we show that it can be sub-optimal. Specifically, when an NPO's services are scalable, the NPO should offer only the service type that generates a higher overall impact. However, when the NPO's services are non-scalable, not only the NPO should offer different types of services, but also raise its advisory effort (when sufficient resources are available).

We suggest practical pathways to help NPOs improve their social impact. NPOs may implement our proposed optimal service design through activities such as hiring and training procedures. Although NPOs typically feel compelled to offer a smorgasbord of services that cater to all types of clients, we identify specific conditions under which the NPO should specialize in a single type of service delivery. In addition, as advisory efforts typically do not produce an immediately visible impact, they are often undervalued in practice. We believe NPOs can employ our analysis to determine whether (and how much) they should invest in providing guidance to their clients and advancing their intake processes. Finally, our model-based analysis can help NPOs adjust their service design as they encounter changes in the demographics of their clients and partnership bases.

Appendices

APPENDIX A

EXAMPLE OF A TRIGGER CARD ISSUED BY AN OPO

<p>ORGAN DONATION CLINICAL TRIGGERS</p> <p>Your patient is intubated and shows evidence of the following:</p> <ul style="list-style-type: none">• Coma• Stroke• Hypoxia• Brain Tumor• Cerebral Injury• Near-Drowning• Cerebral Edema• Cerebral Hemorrhage <p><u>AND</u></p> <p>Any of the following criteria are met:</p> <ul style="list-style-type: none">• GCS≤5, not sedated• Unresponsive or posturing• No pupillary or corneal reflex• No cough or gag• No spontaneous respiration• Discussion of DNR or withdrawal of support

APPENDIX B

PROOFS FOR RESULTS IN CHAPTER 2

Let w_x^χ denote the average wait time in OR queue for each patient class, where: $x \in \{a, h\}$ and priority $\chi \in \mathcal{A}$ in the current scenario; $x \in \{a1, a2, h\}$ and priority $\chi \in \mathcal{A}_S$ in the proposed centralized scenario.

Proof of Proposition 1. From the discussion following (2.3) and (2.4), we have: $w_a^I = \frac{(\lambda_a \nu_a + \lambda_h \nu_h)}{2(1-\rho_a)}$, $w_h^I = \frac{(\lambda_a \nu_a + \lambda_h \nu_h)}{2(1-\rho_a)(1-\rho_h)}$, $w_a^{II} = \frac{(\lambda_a \nu_a + \lambda_h \nu_h)}{2(1-\rho_h)(1-\rho_a-\rho_h)}$, and $w_h^{II} = \frac{(\lambda_a \nu_a + \lambda_h \nu_h)}{2(1-\rho_h)}$. Under Assumption A1, $w_h^\chi \cong \frac{(\lambda_a \nu_a + \lambda_h \nu_h)}{2(1-\rho_h)} \forall \chi \in \mathcal{A}$. Substituting this expression in (3) and (4), we obtain the following relationship: $w_a(f, \chi = I) < w_a(f, \bar{\chi}) < w_a(f, \chi = II) \forall \bar{\chi} \in \mathcal{A} \setminus \{I, II\}$. Since π_h is increasing in w_a , we obtain $\chi_h^* = II$. Substituting the expression for w_a^{II} in place of w_a , and substituting $f = \tau \xi_o^* \xi_h = \tau \theta \xi_h$ in (2.1), we obtain:

$$\frac{\partial \pi_h}{\partial \xi_h} = \left(R_{af} + R_{av} \frac{\lambda_h \nu_h}{2(1-\rho_h)} - c_h \frac{\nu_a}{2(1-\rho_h)} \right) \tau \theta \lambda_p + \xi_h \left(R_{av} \frac{\lambda_p^2 \nu_a (\tau \theta)^2}{1-\rho_h} - c_e \right) =: B + \xi_h A$$

where $A = R_{av} \frac{\lambda_p^2 \nu_a (\tau \theta)^2}{1-\rho_h} - c_e$, and $B = \left(R_{af} + R_{av} \frac{\lambda_h \nu_h}{2(1-\rho_h)} - c_h \frac{\nu_a}{2(1-\rho_h)} \right) \tau \theta \lambda_p$. Denote $\bar{c}_e := R_{av} \frac{\lambda_p^2 \nu_a (\tau \theta)^2}{1-\rho_h}$, and $\bar{c}_h := R_{af} \frac{2(1-\rho_h)}{\nu_a} + R_{av} \frac{\lambda_h \nu_h}{\nu_a}$. Note that $c_e \leq \bar{c}_e \Leftrightarrow A \geq 0$, and $c_h \leq \bar{c}_h \Leftrightarrow B \geq 0$.

When $A < 0$ (or $c_e > \bar{c}_e$), π_h is concave in ξ_h , otherwise it is convex (because $\frac{\partial^2 \pi_h}{\partial \xi_h^2} = A$). Therefore, the hospital's objective and optimal effort level (ξ_h^*) can be characterized by the following four exhaustive cases:

- (i) $c_e > \bar{c}_e$ and $c_h \geq \bar{c}_h$, or $A < 0$ and $B \leq 0 \Rightarrow \frac{\partial \pi_h}{\partial \xi_h} < 0 \Rightarrow \xi_h^* = 0$.
- (ii) $c_e > \bar{c}_e$ and $c_h < \bar{c}_h$, or $A < 0 < B$: (a) $\frac{B}{-A} < 1 \Rightarrow \pi_h$ is concave (unimodal) and $\xi_h^* = \frac{B}{-A} < 1$. (b) $\frac{B}{-A} > 1 \Rightarrow \frac{\partial \pi_h}{\partial \xi_h} \geq 0 \Rightarrow \pi_h$ is concave increasing and $\xi_h^* = 1$.
- (iii) $c_e < \bar{c}_e$ and $c_h < \bar{c}_h$, or $A > 0$ and $B > 0 \Rightarrow \frac{\partial \pi_h}{\partial \xi_h} > 0 \Rightarrow \xi_h^* = 1$.

(iv) $c_e < \bar{c}_e$ and $c_h \geq \bar{c}_h$, or $B \leq 0 < A$: $A > 0$ implies that π_h is convex in ξ_h . The following two sub-cases arise from comparing $\pi_h|_{\xi_h=1}$ and $\pi_h|_{\xi_h=0}$: Denote $\bar{\bar{c}}_h(c_e) = \bar{c}_h + (\bar{c}_e - c_e) \left(\frac{1-\rho_h}{\lambda_p \tau \theta \nu_a} \right)$; Case (a): For $\bar{c}_h \leq c_h < \bar{\bar{c}}_h(c_e)$, $\pi_h|_{\xi_h=1} - \pi_h|_{\xi_h=0} = \frac{A}{2} + B \geq 0 \Rightarrow \xi_h^* = 1$; and, Case (b): For $c_h \geq \bar{\bar{c}}_h(c_e)$, $\pi_h|_{\xi_h=1} - \pi_h|_{\xi_h=0} = \frac{A}{2} + B \leq 0 \Rightarrow \xi_h^* = 0$. Note that if $B = \frac{-A}{2}$, the hospital is indifferent between $\xi_h^* = 1$ and $\xi_h^* = 0$. \square

Proof of Proposition 2. We first show that $\chi^S = I$. Note that, since $w_{a1}^\chi \cong w_{a2}^\chi \forall \chi \in \mathcal{A}_S$, we drop 1 or 2 from the subscript such that w_a^χ denotes the average wait time experienced by authorized donors of either class. Under Assumption A1, $w_h^\chi \cong \frac{(\lambda_a \nu_a + \lambda_h \nu_h)}{2(1-\rho_h)} \forall \chi \in \mathcal{A}$. Since π_S decreases in w_a , and $w_a(f_1, f_2, \chi = II) > w_a(f_1, f_2, \bar{\chi}) > w_a(f_1, f_2, \chi = I) \forall \bar{\chi} \in \mathcal{A}_S \setminus \{I, II\}$, we have $\chi^S = I$.

From the discussion following (2.5) and (2.6), we obtain $w_a^I \cong \frac{f_1 \lambda_{p1} \nu_a + f_2 \lambda_{p2} \nu_a + \lambda_h \nu_h}{2}$. Substituting the expression for w_a^I in place of w_{a1} and w_{a2} in (2.2), we get:

$$\frac{\partial \pi_S}{\partial f_1} = \lambda_{p1} \left(Q_{a1} - Q_{a1} f_1 q_a \lambda_{p1} \nu_a - (Q_{a1} + Q_{a2}) f_2 q_a \frac{\lambda_{p2} \nu_a}{2} - Q_{a1} q_a \frac{\lambda_h \nu_h}{2} - Q_h q_h \frac{\lambda_h \nu_a}{2(1-\rho_h)} \right) \quad (\text{B1})$$

$$\frac{\partial \pi_S}{\partial f_2} = \lambda_{p2} \left(Q_{a1} - Q_{a1} f_2 q_a \lambda_{p2} \nu_a - (Q_{a1} + Q_{a2}) f_1 q_a \frac{\lambda_{p1} \nu_a}{2} - Q_{a1} q_a \frac{\lambda_h \nu_h}{2} - Q_h q_h \frac{\lambda_h \nu_a}{2(1-\rho_h)} \right) \quad (\text{B2})$$

Denoting $\underline{\lambda}_p := \min\{\lambda_{p1}, \lambda_{p2}\}$ and $\bar{\lambda}_p := \max\{\lambda_{p1}, \lambda_{p2}\}$, we consider the three cases in the statement of Proposition 2:

- (i) $q_a < \bar{q}_a := \frac{2Q_{a1}(1-\rho_h) - Q_h q_h \lambda_h \nu_a}{(1-\rho_h)[Q_{a1}(\lambda_h \nu_h + \tau \theta \underline{\lambda}_p \nu_a + 2\tau \theta \bar{\lambda}_p \nu_a) + Q_{a2} \tau \theta \bar{\lambda}_p \nu_a]} \Rightarrow \frac{\partial \pi_S}{\partial f_1} > 0$ and $\frac{\partial \pi_S}{\partial f_2} > 0 \forall f_1 \in [0, \tau \theta]$ and $f_2 \in [0, \tau \theta]$, i.e., $\hat{\pi}_S$ is maximized when $f_1^S = \tau \theta$ and $f_2^S = \tau \theta$.
- (ii) $\bar{q}_a \leq q_a < \bar{\bar{q}}_a := \frac{2Q_{a1}(1-\rho_h) - Q_h q_h \lambda_h \nu_a}{(1-\rho_h)[Q_{a1}(\lambda_h \nu_h + \tau \theta \underline{\lambda}_p \nu_a + 2\tau \theta \bar{\lambda}_p \nu_a) + Q_{a2} \tau \theta \bar{\lambda}_p \nu_a]} \Rightarrow \frac{\partial \pi_S}{\partial f_1} > 0 \forall f_1 \in [0, \tau \theta]$ and $f_2 \in [0, \tau \theta] \Rightarrow f_1^S = \tau \theta$. Also, $\frac{\partial \pi_S}{\partial f_2} \Big|_{f_1=\tau \theta}$ decreases linearly in f_2 such that $\frac{\partial \pi_S}{\partial f_2} \Big|_{f_1=\tau \theta, f_2=0} > 0$ and $\frac{\partial \pi_S}{\partial f_2} \Big|_{f_1=\tau \theta, f_2=\tau \theta} < 0 \Rightarrow \pi_S(f_1 = \tau \theta)$ is unimodal in f_2 and f_2^S can be obtained

by equating $\left. \frac{\partial \pi_S}{\partial f_2} \right|_{f_1=\tau\theta}$ to 0. Therefore,

$$f_2^S = \max \left\{ \frac{(1-\rho_h)[Q_{a1}(2-q_a\lambda_h\nu_h-q_a\tau\theta\lambda_{p1}\nu_a)-Q_{a2}q_a\tau\theta\lambda_{p1}\nu_a]-Q_hq_h\lambda_h\nu_a}{2Q_{a1}(1-\rho_h)q_a\lambda_{p2}\nu_a}, 0 \right\}.$$

(iii) Analogous to (ii) above, when $q_a \geq \bar{q}_a$, we have that π_S is unimodal in $f_1 \forall f_2 \in [0, \tau\theta]$.

Equating $\frac{\partial \pi_S}{\partial f_1}$ to 0, we have $f_1(f_2) = \frac{(1-\rho_h)[Q_{a1}(2-q_a\lambda_h\nu_h-q_a f_2\lambda_{p1}\nu_a)-Q_{a2}q_a f_2\lambda_{p1}\nu_a]-Q_hq_h\lambda_h\nu_a}{2Q_{a1}(1-\rho_h)q_a\lambda_{p1}\nu_a}$.

Substituting this expression in place of f_1 in (??), we have $\frac{\partial \pi_S}{\partial f_2} < 0 \Rightarrow f_2^S = 0$. Replacing f_2 with 0 in the expression for f_1^S , we obtain

$$f_1^S = \min \left\{ \frac{(1-\rho_h)Q_{a1}(2-q_a\lambda_h\nu_h)-Q_hq_h\lambda_h\nu_a}{2Q_{a1}(1-\rho_h)q_a\lambda_{p1}\nu_a}, \tau\theta \right\}.$$

□

Proof of Proposition 3.

(i) *Social optimality of the recommended contractual mechanism:*

Replacing $w_{a1}^S \cong \frac{f_1^S\lambda_{p1}\nu_a+f_2^S\lambda_{p2}\nu_a+\lambda_h\nu_h}{2}$ in (2.8), we have that $\hat{\pi}_h|_{\chi_h=I} > \hat{\pi}_h|_{\chi_h=II}$ iff $p_d > R_{av}(f_1^S\lambda_{p1} + f_2^S\lambda_{p2})$. Denote $\bar{p}_d = R_{av}(f_1^S\lambda_{p1} + f_2^S\lambda_{p2})$. Therefore, under the contract, it follows that $p_d > \bar{p}_d \Rightarrow \hat{\chi}_h^* = I$.

Under Assumption A1, $w_{a1}^\chi \cong w_{a2}^\chi \forall \chi \in \mathcal{A}_S$. After substituting $w_a^I = \frac{f_1\lambda_{p1}\nu_a+f_2\lambda_{p2}\nu_a+\lambda_h\nu_h}{2}$ for w_{a1} and w_{a2} in (2.7), we equate the expressions for $\frac{\partial \hat{\pi}_{opo}}{\partial f_1}$ and $\frac{\partial \hat{\pi}_{opo}}{\partial f_2}$ to the right hand sides of (B1) and (B2), respectively, to ensure that the values of f_1 and f_2 that maximize $\hat{\pi}_{opo}$ are also socially optimal. Thus, we obtain $\alpha = \frac{Q_hq_h\lambda_h\nu_a}{2(1-\rho_h)}$ and we have $\hat{\pi}_S \left(\alpha = \frac{Q_hq_h\lambda_h\nu_a}{2(1-\rho_h)}, p_m, p_d > \bar{p}_d \right) = \pi_S^S$.

(ii) *Strict Pareto improvement for the hospital and the OPO:*

Under the given contractual mechanism, $\frac{\partial \hat{\pi}_h}{\partial \xi_h} = -c_e\xi_h + p_m\lambda_p$. $\frac{\partial^2 \hat{\pi}_h}{\partial \xi_h^2} = -c_e < 0 \Rightarrow \hat{\pi}_h$ is maximized at $\hat{\xi}_h^* = \frac{p_m\lambda_p}{c_e}$. Under the contract, let $f^S := \frac{f_1^S\lambda_{p1}+f_2^S\lambda_{p2}}{\lambda_{p1}+\lambda_{p2}}$ denote the *overall* fraction of potential donors who end up as authorized donors. Substituting f^S and $\hat{\xi}_h^*$ in (2.8) after expanding, we specify the conditions that ensure that the *hospital is strictly*

better-off under the contract (i.e., $\hat{\pi}_h^* - \pi_h^* > 0$) in the following three exhaustive cases:

(a) Conditions Θ_2 (i.e., where $0 < \xi_h^* = \frac{B}{-A} < 1$) and $\tilde{f} < f^S(1 - \rho_h)$: Here, it is sufficient to show that the following inequality holds: $ap_m^2 + bp_m + c \geq 0$, where $a = \lambda_p^2$, $b = -2c_e\lambda_p$, and $c = c_e^2 \frac{B^2}{A^2} - c_e \frac{c_h}{1-\rho_h} \left[f^S(1 - \rho_h) - \left(\tau\theta \frac{B}{-A} \right) \right] \lambda_p \nu_a + 2c_e R_{af} \lambda_p \left[f^S - \left(\tau\theta \frac{B}{-A} \right) \right]$. The discriminant of this quadratic equation is always ≥ 0 . This implies that there exist two real roots. Since the sum of the two roots $= \frac{-b}{a} = \frac{2c_e}{\lambda_p} > 0$, it follows that there exists at least one root (say, p_1) that is $> 0 \Rightarrow ap_m^2 + bp_m + c \geq 0 \forall p_m > p_1$.

(b) Conditions Θ_2 and $\tilde{f} > f^S(1 - \rho_h)$: In this case, the condition that ensures $\hat{\pi}_h^* - \pi_h^* > 0$ can be written as $qp_m^2 + rp_m + s > 0$, where $q = \lambda_p^2$, $r = -2c_e\lambda_p$, $s = -c_e^2 \frac{B^2}{A^2} - c_e R + c_e \frac{c_h}{1-\rho_h} \left(\tau\theta \frac{B}{-A} - f^S \right) \lambda_p \nu_a$, and

$$R = R_{af} \left(\tau\theta \frac{B}{-A} - f^S \right) + R_{av} \frac{\lambda_p}{1 - \rho_h} \left[\left(\tau^2 \theta^2 \frac{B^2}{A^2} - (f^S)^2 (1 - \rho_h) \right) \lambda_p \nu_a + \left(\tau\theta \frac{B}{-A} - f^S (1 - \rho_h) \right) \lambda_h \nu_h \right].$$

By following the same line of reasoning as in case (a) above, we can show that there exists at least one root (say, p_2) that is $> 0 \Rightarrow qp_m^2 + rp_m + s > 0 \forall p_m > p_2$.

(c) Conditions Θ_1 (i.e., where $\xi_h^* = 1$) and $\tilde{f} > f^S(1 - \rho_h)$: Note that conditions Θ_1 imply $\tilde{f} > f^S(1 - \rho_h)$. The proof of case (c) is similar to that of case (b) above, by replacing $\frac{B}{-A}$ with 1. For case (c), let p_3 denote the threshold such that $\hat{\pi}_h^* - \pi_h^* > 0 \forall p_m > p_3$.

Rearranging the terms in the relationships $f_1^S = \tau \hat{\xi}_h^* \hat{\xi}_{o1}^*$ and $f_2^S = \tau \hat{\xi}_h^* \hat{\xi}_{o2}^*$, we have $\hat{\xi}_{o1}^* = \frac{f_1^S}{\tau \hat{\xi}_h^*}$ and $\hat{\xi}_{o2}^* = \frac{f_2^S}{\tau \hat{\xi}_h^*}$. For each of the cases in Proposition 2, it is straightforward to find the corresponding values of the penalty (say, p_4) such that $\hat{\xi}_{o1}^* + \hat{\xi}_{o2}^* < 2\xi_o^* = 2\theta$, or that the *OPO is strictly better-off under the contract* $\forall p_m > p_4$. Strict Pareto improvement for the hospital and the OPO follows by setting $\bar{p}_m = \max \{p_1, p_2, p_3, p_4\}$. \square

APPENDIX C

TABLES FOR CHAPTER 3

Table C.1: Demographics of appointees and nature of CSE appointments

Demographics of CSE appointees	% of Sample
Women (Men)	29.7% (70.3%)
Bachelor's degree as the highest degree	30.6%
Master's degree as the highest degree	55.0%
Ph.D. degree as the highest degree	14.4%
Have an MBA degree	28.8%
Mean (median) years of work experience	22 (21)
Nature of CSE appointment	
Appointed to Newly-created (Existing) position	45.0% (55.0%)
Outsider (Insider)	48.6% (51.4%)
Reporting directly to CEO or COO	30.6%
Not reporting directly to CEO or COO	24.3%
No information on reporting	45.1%

Table C.2: Descriptive statistics based on the most recent fiscal year completed before the announcement of CSE appointment

Measure	Mean	Median	Std. Dev.
Market Value of Equity (million \$)	30,887.7	9,118.0	75,581.8
Total Assets (million \$)	61,386.3	10,372.0	1,67,282.1
Sales (million \$)	23,730.1	7,867.0	45,808.1
Net Income (million \$)	1,635.8	349.2	5,174.1
Return on Assets (%)	2.3	4.0	17.4

Table C.3: Distribution of appointments by year range

Year Range	Number	% of Sample
2000–2003	24	21.6
2004–2007	31	27.9
2008–2011	36	32.4
2012–2016	20	18.0

Table C.4: Distribution of appointments by industry group

Industry Group	SIC Codes	Number	% of Sample
Agriculture and Resource Extracting	0001–1999	11	9.9
Manufacturing	2000–4999	80	72.1
Wholesaling, Retailing, and Services	5000–9999	20	18.0

Table C.5: Distribution of announcements based on categories of specified CSE responsibilities

Category	% of Sample
Ensuring regulatory compliance	40.5
Ensuring occupational and environmental safety and health	32.4
Communicating with key stakeholders	10.8
Developing corporate sustainability strategy	29.7
Building the firm’s sustainability vision and goals	38.7

Table C.6: Summary of Day 0 abnormal returns for 111 sample observations

	Based on announcement-day abnormal returns obtained using		
	Four-Factor Model	Market Model	Market-Adjusted Model
Mean (%)	−0.053	−0.052	−0.165
<i>t</i> -statistic	−0.361	−0.368	−1.099
Median (%)	−0.180	−0.002	−0.089
<i>Z</i> -statistic	−0.699	−0.856	−1.248
Percent greater than zero	45.94	50.0	45.94
<i>p</i> -value	0.505	1.00	0.448

Table C.7: Estimated coefficients (t-statistics in parentheses) from regression analyses

Variables	Model 1	Model 2	Model 3	Model 4
Intercept	-0.0033 (-1.50)	-0.0022 (-0.77)	-0.0035 (-0.29)	-0.0226 (-1.12)
<i>Focused</i>	0.0080 (2.88)***	0.0085 (2.95)***	0.0092 (2.91)***	0.0096 (3.03)***
<i>Prior_Event</i>	0.0095 (3.21)***	0.0076 (2.55)**	0.0074 (2.38)**	0.0079 (2.53)**
<i>Sust_Performance</i>		0.0018 (0.63)	0.0013 (0.35)	-0.00074 (-0.18)
<i>Reg_Sanctions</i>	0.0070 (-2.56)**	-0.0058 (-2.06)**	-0.0055 (-1.85) [†]	-0.0054 (-1.85) [†]
New			0.0019 (0.64)	0.0016 (0.53)
Outsider			0.0007 (0.25)	0.0008 (0.30)
Firm_Size			-0.0002 (-0.19)	0.0009 (0.63)
CEO_Turnover			0.0011 (0.28)	0.0016 0.38)
IMR ^a				0.0103 (1.15)
N	111	92	92	92
F-statistic	8.22***	4.84***	2.40**	2.29**
R ²	18.73%	18.21%	18.78%	20.08%
Adjusted R ²	16.45%	14.45%	10.95%	11.31%

^a Inverse Mills Ratio (details in Section 3.5.3)

Significance levels (two-tailed tests): [†] $p < 0.1$, * $p < 0.05$, ** $p < 0.025$, *** $p < 0.01$

Table C.8: Estimated coefficients (t-statistics in parentheses) from robustness checks

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	0.0023 (0.31)	-0.0001 (-0.01)	-0.0009 (-0.09)	-0.0005 (-0.06)	-0.0052 (-0.52)	-0.0023 (-0.24)
<i>Focused</i>	0.0078 (2.58)**	0.0078 (2.40)**	0.0096 (2.99)***	0.0093 (2.92)***	0.0092 (2.92)***	0.0092 (2.85)***
<i>Prior_Event</i>	0.0073 (2.46)**	0.0084 (2.62)**	0.0063 (1.87) [†]	0.0074 (2.36)**	0.0071 (2.31)**	0.0075 (2.34)**
<i>Sust_Performance</i>	0.0014 (0.41)	0.0015 (0.39)	0.0009 (0.25)	-0.0001 (-0.03)	0.0024 (0.64)	0.0012 (0.30)
<i>Reg_Sanctions</i>	-0.0044 (-1.57)	-0.0057 (-1.88) [†]	-0.0048 (-1.72) [†]	-0.0053 (-1.82) [†]	-0.0053 (-1.80) [†]	-0.0055 (-1.85) [†]
New	0.0013 (0.46)	-0.0004 (-0.12)	0.0021 (0.67)	0.0019 (0.63)	0.0019 (0.52)	0.0019 (0.62)
Outsider	0.0005 (0.18)	0.0024 (0.81)	0.0005 (0.18)	0.0006 (0.21)	0.0002 (0.96)	0.0007 (0.26)
Firm_Size	-0.0007 (-0.68)	-0.0005 (-0.43)	-0.0003 (-0.29)	-0.0005 (-0.50)	-0.0001 (-0.13)	-0.0002 (-0.16)
CEO_Turnover	0.0005 (0.13)	0.0001 (0.04)	0.0019 (0.45)	0.0012 (0.29)	0.0016 (0.38)	0.0011 (0.26)
Time ^a				0.0019 (1.38)		
Gender ^b					-0.0006 (-0.17)	
N	92	92	92	92	92	92
F-statistic	2.26**	2.37**	2.09**	2.38**	2.37**	2.11**
R ²	17.86%	18.60%	16.78%	18.66%	20.63%	18.81%
Adjusted R ²	9.95%	10.76%	8.76%	10.82%	11.92%	9.90%

^b Time takes value corresponding to the ranges in Table C.3, where Time = 0 for 2000-2003, Time = 1 for 2004-2007, and so on.

^b Gender = 1 if the CSE appointee is a female, 0 otherwise.

Significance levels (two-tailed tests): [†] $p < 0.1$, * $p < 0.05$, ** $p < 0.025$, *** $p < 0.01$

APPENDIX D

PROOFS AND TECHNICAL DETAILS OF CHAPTER 4

We first present a few technical results in lemmas that we later use in the proofs of propositions.

Lemma 1. *For the optimization problem outlined in (4.3)–(4.5): (i) the constraint (4.4) binds, i.e., $e_G + e_B + e_A = S$, and (ii) both e_A^* and e_B^* are not equal to zero, simultaneously.*

Proof of Lemma 1: (i) Because the objective function outlined in (4.3) is strictly increasing in both e_A and e_B , the constraint (4.4) binds. (ii) Suppose $e_A^* = 0$ and $e_B^* = 0$. From the result in (i), we obtain that $TEI(S, 0, 0) = 0$. It is straightforward to show that there are other sets of values that delivers $TEI > 0$ (for instance, $e_G = 0$, $e_B = S$, and $e_A = 0$), a contradiction. \square

Lemma 2. *For any $0 < \beta \leq 1$, $0 \leq \alpha \leq 1$, and $e_G^* \geq 0$, we have*

$$(i) \ e_B^*(e_G) = \frac{(S-e_G) \cdot B(e_G)}{1+B(e_G)} \text{ and } e_A^*(e_G) = \frac{S-e_G}{1+B(e_G)}. \text{ where,}$$

$$B(e_G) \doteq \left(\frac{p \cdot (1 - \theta(e_G)) \cdot \alpha \cdot k + (1-p) \cdot \theta(e_G)}{p \cdot \theta(e_G) \cdot k + (1-p) \cdot (1 - \theta(e_G)) \cdot \alpha} \right)^{\frac{1}{1-\beta}} > 0,$$

$$(ii) \text{ there exists a threshold } p_o \doteq \frac{1}{k+1} \text{ such that, } e_A^* > e_B^* \text{ if and only if } p > p_o.$$

Proof of Lemma 2: Using Lemma 1(i) and substituting $e_A = S - e_G - e_B$ in (4.3), the objective $TEI(e_G, e_B)$ remains concave in e_B . Solving $\frac{\partial}{\partial e_B} TEI(e_G, e_B) = 0$ and $e_A = S - e_G - e_B$, we obtain $e_B^*(e_G) = \frac{(S-e_G) \cdot B(e_G)}{1+B(e_G)}$ and $e_A^*(e_G) = \frac{S-e_G}{1+B(e_G)}$ where $B(e_G)$ is as defined in the statement of this lemma. Further, using the expressions of $e_A^*(e_G)$ and $e_B^*(e_G)$, we have that $e_A^* > e_B^*$ if and only if $p > p_o \doteq \frac{1}{k+1}$ (because, $(p\theta(e_G)k + (1-p)(1-\theta(e_G))\alpha) > (p(1-\theta(e_G))\alpha k + (1-p)\theta(e_G))$ if and only if $p > p_o$). \square

Lemma 3. Suppose $\beta = 1$. For any given $e_G \geq 0$, both e_A^* and e_B^* cannot be strictly greater than zero, simultaneously (i.e., either $e_A^* > 0$ or $e_B^* > 0$).

Proof of Lemma 3: Substituting $\beta = 1$, $e_G = S - e_B - e_A$ (by Lemma 1(i)), and $\theta(e_G)$ in (4.3), and twice differentiating it with respect to e_A and e_B , we obtain that the determinant of Hessian of $TEI(e_A, e_B)$ is given by $|H| = -I^2\theta_o^2 \left((1 + \alpha)^2 (p(k + 1) - 1)^2 \right) < 0$. Therefore, it follows that Hessian of $TEI(e_A, e_B)$ is indefinite, which implies that for $\beta = 1$, the objective $TEI(e_A, e_B)$ is not jointly concave in e_A and e_B . Thus, e_A^* and/or e_B^* take corner value at optima. By Lemma 1(ii), we can rule out $e_A^* = e_B^* = 0$ (and, hence, $e_G^* = S$). We thus have the following two possibilities: (i) $e_A^*(e_G) = S - e_G$ and $e_B^* = 0$, or (ii) $e_B^*(e_G) = S - e_G$ and $e_A^* = 0$. \square

Lemma 4. Suppose $\beta = 1$. For any given $e_G \geq 0$, $e_B^* = 0$ if $p > p_o$ and $e_A^* = 0$ if $p \leq p_o$ where $p_o \doteq \frac{1}{k+1}$.

Proof of Lemma 4: For any given $e_G \geq 0$, using the expressions of $e_A^*(e_G)$ and $e_B^*(e_G)$ from Lemma 2, we have:

$$\hat{R} \doteq \frac{e_A^*(e_G)}{e_B^*(e_G)} = \left(\frac{pk\theta(e_G) + (1-p)(1-\theta(e_G))\alpha}{p(1-\theta(e_G))\alpha k + (1-p)\theta(e_G)} \right)^{\frac{1}{1-\beta}}. \quad (D1)$$

Taking limit as β approaches 1, we get $\lim_{\beta \rightarrow 1} \hat{R} = \infty$ if $p > p_o$ and $\lim_{\beta \rightarrow 1} \hat{R} = 0$ if $p \leq \frac{1}{k+1} \doteq p_o$ (because, $(p\theta(e_G)k + (1-p)(1-\theta(e_G))\alpha) > (p(1-\theta(e_G))\alpha k + (1-p)\theta(e_G))$ if and only if $p > p_o$). This implies that $e_B^* = 0$ if $p > p_o$ and $e_A^* = 0$ if $p \leq p_o$. \square

Lemma 5. Suppose $\beta = 1$. Then, (i) if $p > p_o$, there exists a threshold S_1 such that for $S > S_1$, $e_G^* = \frac{S-S_1}{2}$ and $e_A^* = \frac{S+S_1}{2}$, otherwise $e_G^* = 0$ and $e_A^* = S$. (ii) if $p \leq p_o$, there exists a threshold S_2 such that for $S > S_2$, $e_G^* = \frac{S-S_2}{2}$ and $e_B^* = \frac{S+S_2}{2}$, otherwise $e_G^* = 0$ and $e_B^* = S$.

Proof of Lemma 5: (i) Since $p > p_o$, from Lemma 4, we have $e_B^* = 0$. Solving $\frac{\partial TEI(e_G, e_A, 0)}{\partial e_A} = 0$ and $\frac{\partial TEI(e_G, e_A, 0)}{\partial e_G} = 0$, we obtain $e_G^* = \frac{S-S_1}{2}$ and $e_A^* = \frac{S+S_1}{2}$, where, $S_1 \doteq \frac{\theta}{\theta_o} \left(\frac{pk + \alpha(1-p)\left(\frac{1-\theta}{\theta}\right)}{pk - \alpha(1-p)} \right)$.

Given the non-negativity constraint in (4.5), it follows that $e_G^* > 0$ if and only if $S > S_1$; otherwise, $e_G^* = 0$.

(ii) Since $p \leq p_o$, from Lemma 4, we have $e_A^* = 0$. Solving $\frac{\partial TEI(e_G, 0, e_B)}{\partial e_B} = 0$ and $\frac{\partial TEI(e_G, 0, e_B)}{\partial e_G} = 0$, we obtain $e_G^* = \frac{S-S_2}{2}$ and $e_B^* = \frac{S+S_2}{2}$, where, $S_2 \doteq \frac{\theta}{\theta_o} \left(\frac{1-p+\alpha pk \left(\frac{1-\theta}{\theta} \right)}{1-p-\alpha pk} \right)$.

Given the non-negativity constraint in (4.5), it follows that $e_G^* > 0$ if and only if $S > S_2$; otherwise, $e_G^* = 0$. \square

D.1 Proofs and Technical Details of Section 4.4.1

Proof of Proposition 4: Using results in Lemma 5, it follows that $e_G^* = \frac{S-\hat{S}}{2} > 0$ if and only if $S > \hat{S}$, where \hat{S} is as defined in (4.6). In addition, by Lemma 4, we have that $e_B^* = 0$ if $p > p_o$ and $e_A^* = 0$ if $p \leq p_o$. \square

Proof of Corollary 1: (i) Using equation (4.6) and differentiating \hat{S} with respect to α , we obtain

$$\frac{d}{d\alpha} \hat{S}(\alpha) = \frac{pk(1-p)}{\theta_o (\max\{pk, 1-p\} - \min\{pk, 1-p\} \alpha)^2} > 0,$$

in which the inequality holds because $0 < p < 1$ and $k \geq 1$.

(ii) Using equation (4.6) and differentiating \hat{S} with respect to p , we obtain that for $p > p_o$, $\frac{d}{dp} \hat{S}(p) = \frac{-\alpha k}{\theta_o (pk - (1-p)\alpha)^2} < 0$; however, for $p \leq p_o$, $\frac{d}{dp} \hat{S}(p) = \frac{\alpha k}{\theta_o (1-p(\alpha k+1))^2} > 0$, where the inequalities hold because $0 < \alpha < 1$ and $k \geq 1$.

(iii) Using equation (4.6) and differentiating \hat{S} with respect to k , we obtain that for $p > p_o$, $\frac{d}{dk} \hat{S}(k) = \frac{-p(1-p)\alpha \left(\frac{1-\theta}{\theta} \right)}{\theta_o (pk - (1-p)\alpha)^2} < 0$; however, for $p \leq p_o$, $\frac{d}{dk} \hat{S}(k) = \frac{p(1-p)\alpha \left(\frac{1-\theta}{\theta} \right)}{\theta_o (1-p(\alpha k+1))^2} > 0$, where the inequalities hold because $0 < \alpha < 1$ and $k \geq 1$. \square

Proof of Corollary 2: Using the results of Proposition 4, we obtain that for $S \leq \hat{S}$, $e_A^* + e_B^* = S > 0 = e_G^*$, and for $S > \hat{S}$, $e_A^* + e_B^* = \frac{S+\hat{S}}{2} > \frac{S-\hat{S}}{2} = e_G^*$.

(i) By Corollary 1, \hat{S} is increasing in α , which implies that there exists a threshold $\bar{\alpha}$ such $S > \hat{S}$ if and only if $\alpha < \bar{\alpha}$. Consequently, by Proposition 4, $e_G^* > 0$ if $\alpha < \bar{\alpha}$ and $e_G^* = 0$ otherwise.

Using $e_G^* > 0$ as characterized in Proposition 4, we obtain $\frac{d}{d\alpha} e_G^*(\alpha) = -\frac{1}{2} \left(\frac{d}{d\alpha} \hat{S}(\alpha) \right) < 0$.

(ii) Using $e_A^* > 0$ or $e_B^* > 0$ as characterized in Proposition 4, we obtain $\frac{d}{d\alpha}e_A^*(\alpha) = \frac{1}{2} \left(\frac{d}{d\alpha}\hat{S}(\alpha) \right) > 0$. In addition, by the proof of part (ii), e_A^* (or e_B^*) is equal to S for $\alpha \geq \bar{\alpha}$, given that $e_G^* = 0$ and that e_A^* and e_B^* cannot simultaneously be strictly greater than zero (by Lemma 3). \square

D.2 Proofs and Technical Details of Section 4.4.2

Proof of Proposition 5: By Lemma 1(i), constraint (4.4) binds. Substituting $e_G = S - e_A - e_B$, $\theta(e_G) = \underline{\theta} + \theta_o \cdot e_G$, and $\alpha = 0$ in (4.3), and differentiating it with respect to e_A and e_B , we obtain:

$$\begin{aligned} \frac{\partial}{\partial e_A} TEI(e_A, e_B) = & \frac{\underline{\theta} \cdot I}{(e_A)^{1-\beta}} \cdot \left[\left(1 + \frac{\theta_o \cdot S}{\underline{\theta}} \right) \cdot p \cdot k - (1 + \beta) \cdot \frac{\theta_o}{\underline{\theta}} \cdot p \cdot k \cdot e_A \right. \\ & \left. - \frac{\theta_o}{\underline{\theta}} \cdot p \cdot k \cdot e_B - (1 - p) \cdot \frac{\theta_o}{\underline{\theta}} \cdot (e_A)^{1-\beta} \cdot (e_B)^\beta \right], \end{aligned} \quad (D2)$$

$$\begin{aligned} \frac{\partial}{\partial e_B} TEI(e_A, e_B) = & \frac{\underline{\theta} \cdot I}{(e_B)^{1-\beta}} \cdot \left[\left(1 + \frac{\theta_o \cdot S}{\underline{\theta}} \right) \cdot (1 - p) - (1 + \beta) \cdot \frac{\theta_o}{\underline{\theta}} \cdot (1 - p) \cdot e_B \right. \\ & \left. - \frac{\theta_o}{\underline{\theta}} \cdot (1 - p) \cdot e_A - \frac{\theta_o}{\underline{\theta}} \cdot p \cdot k \cdot (e_B)^{1-\beta} \cdot (e_A)^\beta \right]. \end{aligned} \quad (D3)$$

Since $\lim_{e_A \rightarrow 0^+} \frac{\partial}{\partial e_A} TEI(e_A, e_B) > 0$ (because $e_B \leq S$) and $\lim_{e_B \rightarrow 0^+} \frac{\partial}{\partial e_B} TEI(e_A, e_B) > 0$ (because $e_A \leq S$), we have that $e_A^* > 0$ and $e_B^* > 0$. Thus, there exist interior solutions for e_A^* and e_B^* , which can be obtained by solving the two first order conditions.

(i) On solving (D2)–(D3) and $e_G = S - e_A - e_B$, we obtain the following unique set of feasible solutions: $e_A^* = \left(\frac{\beta}{1+\beta} \right) \left(S + \frac{\underline{\theta}}{\theta_o} \right) \left(\frac{(p \cdot k)^{\frac{1}{1-\beta}}}{(p \cdot k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right)$, $e_B^* = \left(\frac{\beta}{1+\beta} \right) \left(S + \frac{\underline{\theta}}{\theta_o} \right) \left(\frac{(1-p)^{\frac{1}{1-\beta}}}{(p \cdot k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right)$, and $e_G^* = \left(\frac{1}{1+\beta} \right) \left(S - \frac{\beta \cdot \underline{\theta}}{\theta_o} \right)$. This constructs the NPO's optimal efforts if and only if $S > \frac{\beta \cdot \underline{\theta}}{\theta_o} \doteq \tilde{S}$ (given the non-negativity constraint on e_G).

Next, suppose $S \leq \tilde{S}$. Substituting $e_G = 0$ in (4.3) and re-solving the first order conditions for e_A and e_B , we obtain $e_G^* = 0$, $e_A^* = \frac{S(p \cdot k)^{\frac{1}{1-\beta}}}{(p \cdot k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}}$, and $e_B^* = \frac{S(1-p)^{\frac{1}{1-\beta}}}{(p \cdot k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}}$.

(ii) Comparing the expressions for e_A^* and e_B^* in the two scenarios above (for $S > \tilde{S}$ and

$S \leq \tilde{S}$), we have

$$\tilde{R} \doteq \frac{e_A^*}{e_B^*} = \left(\frac{p \cdot k}{1-p} \right)^{\frac{1}{1-\beta}}. \quad (\text{D4})$$

Thus, since $\beta \in (0, 1)$, we obtain that $e_A^* > e_B^*$ if and only if $p > \frac{1}{k+1} \doteq p_o$. \square

Proof of Corollary 3: Using the results of Proposition 5, and substituting the expressions for (e_G^*, e_A^*, e_B^*) for when $S > \tilde{S}$ (i.e., $\beta < \frac{S\theta_o}{\underline{\theta}}$), we obtain that $e_G^* > e_A^* + e_B^*$ if and only if $\beta < \frac{S\theta_o}{2\underline{\theta} + S\theta_o}$. In addition, for $S \leq \tilde{S}$ (i.e., $\beta \geq \frac{S\theta_o}{\underline{\theta}}$), we obtain that $e_G^* = 0 < e_A^* + e_B^*$. These results imply that there exists a unique threshold $\beta_o \doteq \min \left\{ \frac{S\theta_o}{2\underline{\theta} + S\theta_o}, \frac{S\theta_o}{\underline{\theta}} \right\} = \frac{S\theta_o}{2\underline{\theta} + S\theta_o}$ such that $e_G^* > e_A^* + e_B^*$ if and only if $\beta < \beta_o$.

(i) Consider $S > \tilde{S}$. Using the results of Proposition 5 and differentiating efforts with respect to β , we obtain

$$\frac{d}{d\beta} e_G^*(\beta) = \frac{-1}{(1+\beta)^2} \left(S + \frac{\theta}{\theta_o} \right) < 0, \quad (\text{D5})$$

$$\frac{d}{d\beta} e_A^*(\beta) = \frac{S \left((1+\beta) \tilde{R} \ln(\tilde{R}) + \tilde{R} (1+\tilde{R}) \right)}{\left((1+\beta) (1+\tilde{R}) \right)^2}, \quad (\text{D6})$$

$$\frac{d}{d\beta} e_B^*(\beta) = \frac{S\beta \left((1-\beta) (1+\tilde{R}) - (1+\beta) \tilde{R} \ln(\tilde{R}) \right)}{\left((1+\beta) (1+\tilde{R}) \right)^2}, \quad (\text{D7})$$

where \tilde{R} is as defined in (D4). Because $\beta \in (0, 1)$, and $\ln(\tilde{R}) > 0$ if and only if $p > p_o$, from (D6) and (D7), it follows that: $\frac{d}{d\beta} e_A^*(\beta) > 0$ if $p > p_o$ and $\frac{d}{d\beta} e_B^*(\beta) > 0$ if $p < p_o$. For other ranges of p , we can show that the second derivative of e_A^* and e_B^* with respect to β are negative. Differentiating (D7) with respect to β , we obtain

$$\frac{d^2}{d\beta^2} e_B^*(\beta) = \frac{-S\beta \left((1-\beta) (1+\tilde{R}) + (1+\beta) \tilde{R} \ln(\tilde{R}) (1 + \ln(\tilde{R})) \right)}{\left((1+\beta) (1+\tilde{R}) \right)^2}. \quad (\text{D8})$$

Because $\beta \in (0, 1)$, and $\ln(\tilde{R}) \geq 0$ when $p \geq p_o$, $\frac{d^2}{d\beta^2} e_B^*(\beta) < 0$ for $p \geq p_o$. Therefore, we can conclude that $e_B^*(\beta)$ is concave in β for $p \geq p_o$. Similar result holds for e_A^* and when $p < p_o$.

(ii) Consider $S \leq \tilde{S}$. Using the results of Proposition 5 and differentiating e_A^* and e_B^* with

respect to β , we obtain

$$\frac{d}{d\beta} e_A^*(\beta) = \frac{S}{((1-\beta)(1+\tilde{R}))^2} \left(\frac{p.k}{1-p} \right)^{\frac{1}{1-\beta}} \ln \left(\frac{p.k}{1-p} \right),$$

$$\frac{d}{d\beta} e_B^*(\beta) = \frac{-S}{((1-\beta)(1+\tilde{R}))^2} \left(\frac{p.k}{1-p} \right)^{\frac{1}{1-\beta}} \ln \left(\frac{p.k}{1-p} \right).$$

Because $\beta \in (0, 1)$, and $\ln \left(\frac{p.k}{1-p} \right) > 0$ if and only if $p > p_o$, it follows that $e_A^*(\beta)$ is increasing in β if and only if $p > p_o$, and $e_B^*(\beta)$ is decreasing in β if and only if $p > p_o$. \square

D.3 Proofs and Technical Details of Section 4.5.1

Lemma 6. Consider $f(S, \xi_B) \doteq \frac{1}{S^{1-\beta}} \left(S - \frac{\beta\theta}{\theta_o} \right) + \left(\frac{1-p}{p.k} \right) (\xi_B)^\beta$. Then (i) $f \left(\frac{\beta\theta}{\theta_o} - \xi_B, \xi_B \right) > 0$ if and only if $\xi_B > \frac{\beta\theta}{\theta_o} \left(\frac{(1-p)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right)$, (ii) $f(S, \xi_B)$ is increasing in both ξ_B and S .

Proof of Lemma 6: (i) Substituting $S = \frac{\beta\theta}{\theta_o} - \xi_B$ in $f(S, \xi_B)$, we get:

$$\begin{aligned} f \left(\frac{\beta\theta}{\theta_o} - \xi_B, \xi_B \right) &= \frac{-\xi_B}{\left(\frac{\beta\theta}{\theta_o} - \xi_B \right)^{1-\beta}} + \left(\frac{1-p}{p.k} \right) (\xi_B)^\beta \\ &= -(\xi_B)^\beta \left(\left(\frac{\beta\theta}{\theta_o \xi_B} - 1 \right)^{\frac{1}{1-\beta}} - \left(\frac{1-p}{p.k} \right) \right). \end{aligned} \quad (\text{D9})$$

Since $\xi_B > 0$, (D9) is strictly greater than zero if and only if $\left(\frac{\beta\theta}{\theta_o \xi_B} - 1 \right)^{\frac{1}{1-\beta}} - \left(\frac{1-p}{p.k} \right) < 0$, which is equivalent to $\xi_B > \frac{\beta\theta}{\theta_o} \left(\frac{(1-p)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right)$.

(ii) By differentiating $f(S, \xi_B)$ with respect to ξ_B and S , we obtain: $\frac{d}{d\xi_B} f(S, \xi_B) = \beta \cdot \left(\frac{1-p}{p.k} \right) (\xi_B)^{\beta-1} > 0$, and $\frac{d}{dS} f(S, \xi_B) = \frac{\beta}{S^{1-\beta}} + \frac{(1-\beta)\beta\theta}{\theta_o S^{2-\beta}} > 0$. \square

Proof of Proposition 6: Similar to the result in Lemma 1(i), the constraint (4.8) binds, which combined with constraint (4.9), implies that $e_B \geq \xi_B$. Following same steps as in the proof of Proposition 5, i.e., by substituting $e_G = S + \xi_B - e_A - e_B$ and solving the two

first-order conditions with respect to e_A and e_B , we obtain:

$$\bar{e}_B = \left(\frac{\beta}{1+\beta} \right) \cdot \left(S + \xi_B + \frac{\theta}{\theta_o} \right) \cdot \left(\frac{(1-p)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right), \quad (\text{D10})$$

$$\bar{e}_A = \left(\frac{\beta}{1+\beta} \right) \cdot \left(S + \xi_B + \frac{\theta}{\theta_o} \right) \cdot \left(\frac{(p.k)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right), \quad (\text{D11})$$

$$\bar{e}_G = \left(\frac{1}{1+\beta} \right) \cdot \left(S + \xi_B - \frac{\beta.\theta}{\theta_o} \right). \quad (\text{D12})$$

Let us denote,

$$\tilde{\xi}_{B1}(S) \doteq \min \{ \xi_B | \bar{e}_G \geq 0 \} = \frac{\beta.\theta}{\theta_o} - S = \tilde{S} - S \quad (\text{D13})$$

$$\tilde{\xi}_{B2}(S) \doteq \min \{ \xi_B | \bar{e}_B < \xi_B \} = \left(S + \frac{\theta}{\theta_o} \right) \cdot \left(\frac{\beta.(1-p)^{\frac{1}{1-\beta}}}{(1+\beta).(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right) > 0 \quad (\text{D14})$$

$$\tilde{\xi}_{B3} \doteq \min \left\{ \xi_B | f \left(\frac{\beta.\theta}{\theta_o} - \xi_B, \xi_B \right) > 0 \right\} = \frac{\beta.\theta}{\theta_o} \cdot \left(\frac{(1-p)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right) > 0 \quad (\text{D15})$$

$$\tilde{\xi}_{B4}(S) \doteq \min \{ \xi_B | \bar{e}_A < S \} = \frac{S.(1-p)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}}} > 0 \quad (\text{D16})$$

Comparing $\tilde{\xi}_{B1}(S)$ and $\tilde{\xi}_{B2}(S)$, we obtain that there exists a unique threshold $\tilde{S}_o > 0$ such that, $\tilde{\xi}_{B2}(S) > \tilde{\xi}_{B1}(S)$ if and only if $S > \tilde{S}_o$, where

$$\tilde{S}_o \doteq \frac{\beta\theta}{\theta_o} \left(\frac{(pk)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \right). \quad (\text{D17})$$

In addition, comparing $\tilde{\xi}_{B3}$ with $\tilde{\xi}_{B1}(S)$ and $\tilde{\xi}_{B2}(S)$, there are only two feasible permutations for these thresholds: (a) $\tilde{\xi}_{B2}(S) > \tilde{\xi}_{B3} > \tilde{\xi}_{B1}(S)$ if $S > \tilde{S}_o$, and (b) $\tilde{\xi}_{B2}(S) \leq \tilde{\xi}_{B3} \leq \tilde{\xi}_{B1}(S)$ if $S \leq \tilde{S}_o$. Further, we have that $\tilde{S}_o < \tilde{S} = \frac{\beta.\theta}{\theta_o}$ because $(p.k)^{\frac{1}{1-\beta}} < (p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}$.

Next, consider the following two possible scenarios:

(a) Suppose $S > \tilde{S}_o$ (i.e., $\tilde{\xi}_{B2}(S) > \tilde{\xi}_{B3} > \tilde{\xi}_{B1}(S)$). Based on the magnitude of ξ_B , we have the following three exhaustive cases: (a-i) $0 < \xi_B \leq \tilde{\xi}_{B1}(S)$, (a-ii) $\tilde{\xi}_{B1}(S) < \xi_B < \tilde{\xi}_{B2}(S)$, and (a-iii) $\xi_B \geq \tilde{\xi}_{B2}(S)$.

(a-i). Suppose $0 < \xi_B \leq \tilde{\xi}_{B1}(S)$. By the definition of $\tilde{\xi}_{B1}(S)$ in (D13), $\bar{e}_G \leq 0$, which violates the non-negativity constraint on e_G . Substituting $e_G^* = 0$, $e_B = S - e_A$, and $\alpha = 0$ in (4.3), the objective function $TEI(e_A)$ remains concave in e_A for $\beta \in (0, 1)$. Thus, by the first order conditions, we obtain: $e_A^* = \min \left\{ \frac{(S+\xi_B)(pk)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}}, S \right\}$ and thus $e_B^* = \max \left\{ \frac{(S+\xi_B)(1-p)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}}, \xi_B \right\}$. We next show that $e_B^* > \xi_B$. We have

$$\begin{aligned} \frac{(S + \xi_B) \cdot (1-p)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} - \xi_B &= \frac{(pk)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \cdot \left(\frac{S \cdot (1-p)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}}} - \xi_B \right) \\ &> \frac{(pk)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \cdot \left(\frac{S \cdot (1-p)^{\frac{1}{1-\beta}}}{(pk)^{\frac{1}{1-\beta}}} - \tilde{\xi}_{B2}(S) \right) \\ &= \frac{(1-p)^{\frac{1}{1-\beta}}}{(1+\beta) \cdot (pk)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}} \cdot (S - \tilde{S}_o) > 0, \end{aligned}$$

in which the first inequality holds because $\xi_B < \tilde{\xi}_{B2}(S)$ and the second inequality holds because $S > \tilde{S}_o$. This implies that $e_B^* > \xi_B$.

(a-ii). Suppose $\tilde{\xi}_{B1}(S) < \xi_B \leq \tilde{\xi}_{B2}(S)$. Then, by the definition of $\tilde{\xi}_{B1}(S)$ in (D13), we have $\bar{e}_G > 0$. Similarly, by definition of $\tilde{\xi}_{B2}(S)$ in (D14), we have $\bar{e}_B \geq \xi_B$. Further, similar to the proof of Proposition 5, we can show that $\lim_{e_A \rightarrow 0^+} \frac{\partial}{\partial e_A} TEI(e_A, e_B) > 0$ and $\lim_{e_B \rightarrow 0^+} \frac{\partial}{\partial e_B} TEI(e_A, e_B) > 0$. These results imply that the solution set given by (D10)–(D12) is optimal, i.e., $e_A^* = \bar{e}_A$, $e_B^* = \bar{e}_B$, and $e_G^* = \bar{e}_G$.

(a-iii). Suppose $\xi_B > \tilde{\xi}_{B2}(S)$. Then, by the definition of $\tilde{\xi}_{B2}(S)$ in (D14), we have that $\bar{e}_B < \xi_B$, which violates the earmarked constraint. Substituting $e_B^* = \xi_B$, $e_A = S - e_G$, and $\alpha = 0$ in (4.3), the objective function $TEI(e_A)$ becomes concave in e_G . Thus, by the first order condition, e_G^* solves the following:

$$\frac{d}{de_G} TEI(e_G) = Ip k \left((S - e_G)^{\beta-1} (\theta_o S - \underline{\theta} \beta - \theta_o e_G (1 + \beta)) + \theta_o \left(\frac{1-p}{pk} \right) (\xi_B)^\beta \right). \quad (D18)$$

We next show that $e_G^* > 0$ for all $\xi_B > \tilde{\xi}_{B2}(S)$. To that end, we first show that

$e_G^* > 0$ when $\xi_B = \tilde{\xi}_{B2}(S)$. Substituting $\xi_B = \tilde{\xi}_{B2}(S)$ in (D18), we obtain that e_G^* is equivalent to \bar{e}_G as defined in (D12). In addition, we have that $\left. \frac{d}{de_G} TEI(e_G) \right|_{e_G=0} = Ipk\theta f(S, \xi_B)$, where $f(S, \xi_B)$ is defined in Lemma 6. Given that $f(S, \xi_B)$ is increasing in ξ_B (by Lemma 6(ii)), $\left. \frac{d}{de_G} TEI(e_G) \right|_{e_G=0}$ is increasing in ξ_B , which implies that $\left. \frac{d}{de_G} TEI(e_G) \right|_{e_G=0} > 0$ for $\xi_B > \tilde{\xi}_{B2}(S)$. This combined with the fact that $TEI(e_G)$ is concave in e_G , implies that $e_G^* > 0$ for all $\xi_B > \tilde{\xi}_{B2}(S)$.

The above three cases imply that when $S > \tilde{S}_o$, $e_G^* > 0$ if and only if $\xi_B > \tilde{\xi}_{B1}(S)$ (or, $\xi_B + S > \tilde{S} \doteq \tilde{S}$). Further, $e_B^* > \xi_B$ if and only if $\xi_B < \tilde{\xi}_B(S) \doteq \tilde{\xi}_{B2}(S)$, otherwise, $e_B^* = \xi_B$. From (D14), we have that $\frac{d}{dS} \tilde{\xi}_{B2}(S) > 0$, which implies that $\tilde{\xi}_{B2}(S)$ increases in S .

(b) Suppose $S \leq \tilde{S}_o$ (i.e., $\tilde{\xi}_{B2}(S) \leq \tilde{\xi}_{B3} \leq \tilde{\xi}_{B1}(S)$). By comparing $\tilde{\xi}_{B2}(S)$ and $\tilde{\xi}_{B4}(S)$, we obtain that $\tilde{\xi}_{B4}(S) \leq \tilde{\xi}_{B2}(S)$ if $S \leq \tilde{S}_o$. Therefore, under this case, we have $\tilde{\xi}_{B4}(S) \leq \tilde{\xi}_{B2}(S) \leq \tilde{\xi}_{B3} \leq \tilde{\xi}_{B1}(S)$. Based on the magnitude of ξ_B , we have the following four exhaustive cases: (b-i) $0 < \xi_B < \tilde{\xi}_{B4}(S)$, (b-ii) $\tilde{\xi}_{B4}(S) \leq \xi_B \leq \tilde{\xi}_{B2}(S)$, (b-iii) $\tilde{\xi}_{B2}(S) < \xi_B < \tilde{\xi}_{B3}$, and (b-iv) $\xi_B \geq \tilde{\xi}_{B3}$.

(b-i). Suppose $0 < \xi_B < \tilde{\xi}_{B4}(S)$. Then, by the definition of $\tilde{\xi}_{B1}(S)$ in (D13), we have $\bar{e}_G \leq 0$, which violates the non-negativity constraint on e_G . Thus, similar to part (a-i), we obtain $e_G^* = 0$ and $e_A^* = \min \left\{ \frac{(S+\xi_B) \cdot (p.k)^{\frac{1}{1-\beta}}}{(p.k)^{\frac{1}{1-\beta}} + (1-p)^{\frac{1}{1-\beta}}}, S \right\}$. Similar to part (a-i), it can be shown that $e_A^* < S$. Hence, $e_B^* = S + \xi_B - e_A^* > \xi_B$.

(b-ii). Suppose $\tilde{\xi}_{B4}(S) \leq \xi_B \leq \tilde{\xi}_{B2}(S)$. Because $\xi_B \leq \tilde{\xi}_{B2}(S) \leq \tilde{\xi}_{B1}(S)$, using the same arguments as in case (b-i) above, $e_G^* = 0$. Substituting that and solving the optimization problem, we obtain $e_A^* = S$ and $e_B^* = \xi_B$.

(b-iii). Suppose $\tilde{\xi}_{B2}(S) < \xi_B \leq \tilde{\xi}_{B3}$. Then, by the definition of $\tilde{\xi}_{B2}(S)$ in (D14), we have that $\bar{e}_B < \xi_B$, which violates the earmarked constraint. We therefore re-solve the optimization problem by setting $e_B^* = \xi_B$. Following the same steps as in case (a-iii) above, we conclude that $TEI(e_G)$ is concave in e_G . We next show that $\left. \frac{d}{de_G} TEI(e_G) \right|_{e_G=0} \leq 0$ when $\xi_B \leq \tilde{\xi}_{B3}$.

Note that $\xi_B \leq \tilde{\xi}_{B3} \leq \tilde{\xi}_{B1}(S) = \tilde{S} - S$. Therefore, we have that $\xi_B \leq \tilde{S} - S$ (which is equivalent to $S \leq \tilde{S} - \xi_B$). Suppose, $\xi_B = \tilde{S} - S$. Since $\xi_B \leq \tilde{\xi}_{B3}$ and $S = \tilde{S} - \xi_B$, by result in Lemma 6(i) we have that $f(S, \xi_B) = f(\tilde{S} - \xi_B, \xi_B) \leq 0$. In addition, from the result in Lemma 6(ii), it follows that $f(S, \xi_B) \leq 0$ for all $\xi_B \leq \tilde{\xi}_{B3} \leq \tilde{S} - S$. Therefore, it follows that $\left. \frac{d}{de_G} TEI(e_G) \right|_{e_G=0} \leq 0$ for all $\xi_B \leq \tilde{\xi}_{B3}$. This combined with the fact that $TEI(e_G)$ is concave in e_G , implies that $e_G^* = 0$ (and, $e_A^* = S$) under this case.

(b-iv). Suppose $\xi_B > \tilde{\xi}_{B3}$. Since $\xi_B > \tilde{\xi}_{B3} \geq \tilde{\xi}_{B2}(S)$, by the definition of $\tilde{\xi}_{B2}(S)$, we have that $\bar{e}_B < \xi_B$. This violates the earmarked constraint. Thus, similar to case (a-iii), we can show that there exists a threshold $\tilde{\xi}_{B5}(S)$ (where $\tilde{\xi}_{B3} < \tilde{\xi}_{B5}(S) \leq \tilde{S} - S$ and $f(S, \tilde{\xi}_{B5}(S)) = 0$) such that $e_G^* > 0$ if and only if $\xi_B > \tilde{\xi}_{B5}(S)$. Note that $S + \tilde{\xi}_{B5}(S) \leq \tilde{S}$.

The above three cases imply that when $S \leq \tilde{S}_o$, $e_G^* > 0$ if and only if $\xi_B > \tilde{\xi}_{B5}(S)$ (or, $S + \xi_B > \tilde{S} \doteq \tilde{\xi}_{B5}(S) + S$). Further, $e_B^* > \xi_B$ if and only if $\xi_B < \tilde{\xi}_B(S) \doteq \tilde{\xi}_{B4}(S)$, otherwise, $e_B^* = \xi_B$. From (D16), we have that $\frac{d}{dS} \tilde{\xi}_{B4}(S) > 0$, which implies that $\tilde{\xi}_{B4}(S)$ increases in S . □

D.4 Proofs and Technical Details of Section 4.5.2

Proof of Proposition 7: Substituting $e_G = S - e_A - e_B$ in (4.10) and differentiating it with respect to e_A and e_B , we obtain

$$\begin{aligned} \frac{\partial}{\partial e_A} TEI(e_A, e_B) = & p \cdot (\underline{\theta} + \theta_o \cdot (S - e_A - e_B)) \cdot \beta_A \cdot k \cdot I \cdot (e_A)^{\beta_A - 1} \\ & - p \cdot \theta_o \cdot k \cdot I \cdot (e_A)^{\beta_A} - (1 - p) \cdot \theta_o \cdot I \cdot e_B^{\beta_B}, \end{aligned} \quad (D19)$$

$$\begin{aligned} \frac{\partial}{\partial e_B} TEI(e_A, e_B) = & (1 - p) \cdot (\underline{\theta} + \theta_o \cdot (S - e_A - e_B)) \cdot I \cdot (e_B)^{\beta_B - 1} \\ & - p \cdot \theta_o \cdot k \cdot I \cdot (e_A)^{\beta_A} - (1 - p) \cdot \theta_o \cdot I \cdot e_B^{\beta_B}. \end{aligned} \quad (D20)$$

On solving the resulting system of first order conditions in (D19) and (D20), we obtain the followings:

$$e_G(e_B) e_A(e_B) = e_B^{\frac{1-\beta_B}{1-\beta_A}} \left(\frac{\beta_A k p}{\beta_B (1-p)} \right)^{\frac{1}{1-\beta_A}} \text{ and } e_G(e_B) = S - e_B - e_B^{\frac{1-\beta_B}{1-\beta_A}} \left(\frac{\beta_A k p}{\beta_B (1-p)} \right)^{\frac{1}{1-\beta_A}}.$$

Replacing the above equations in (D20), we obtain that e_B^* solves $f(e_B) = 0$ where $f(e_B)$ is as in (4.11). We next show that e_B^* is unique. Taking the derivative of $f(e_B)$ and evaluating it at all solutions to $f(e_B) = 0$, we obtain

$$f'(e_B) |_{f(e_B)=0} = \underline{\theta} (\beta_B + 1) (\beta_A - \beta_B) e_B^{\beta_B+1} - \beta_B e_B^{\beta_B} (1 - \beta_B) (S\underline{\theta} + \theta_o) < 0,$$

where the inequality holds because by assumption $\beta_A \leq \beta_B < 1$. This implies that the function $f(e_B)$ is decreasing in all its crossing points with zero. Given that $f(e_B)$ is a continuous function of e_B , it can only cross zero once and that crossing will be from above. We can therefore conclude that e_B^* is the unique solution to $f(e_B) = 0$. In addition, $e_G^* = e_G(e_B^*) > 0$ if and only if $S > S_G \doteq e_B^* + (e_B^*)^{\frac{1-\beta_B}{1-\beta_A}} \left(\frac{\beta_A k p}{\beta_B (1-p)} \right)^{\frac{1}{1-\beta_A}}$. In that case, the optimal efforts are as follows: $(e_G^*, e_A^*, e_B^*) = (e_G(e_B^*), e_A^*(e_B^*), e_B^*)$.

Next, consider the case where $S \leq S_G$ which implies $e_G^* = 0$. Replacing $e_A = S - e_B$ in (4.10) and taking its derivative with respect to e_B , we obtain that e_B^* solves the following:

$$e_B + \left(\frac{\beta_A k p}{\beta_B (1-p)} \right)^{\frac{1}{1-\beta_A}} e_B^{1-\beta} - S = 0. \quad (\text{D21})$$

Given that the left hand side of (D21) is increasing in e_B , we conclude that e_B^* is unique, and the optimal efforts are as follows: $(e_G^*, e_A^*, e_B^*) = (0, S - e_B^*, e_B^*)$. \square

D.5 Proofs and Technical Details of Section 4.5.3

Proof of Proposition 8: Substituting $e_G = S - e_B - e_A$ and $\theta(e_G)$ in (4.12), and twice differentiating the resultant $TEI(e_A, e_B)$ with respect to e_A and e_B , we have that determi-

nant of Hessian of $TEI(e_A, e_B)$ is given by $H_o| = -I^2\theta_o^2(p(1+\alpha)(k+1) - (1-p))^2 < 0$.

Applying the same reasoning as in proof of Lemma 3, we can show that the possibilities for point of optimality (where, $0 \leq e_G < S$) are: (i) $e_A^*(e_G) = S - e_G$ and $e_B^* = 0$, or (ii) $e_B^*(e_G) = S - e_G$ and $e_A^* = 0$. We next consider these two cases:

(i) Suppose $e_B^* = 0$. Solving $\frac{\partial TEI(e_G, e_A, 0)}{\partial e_A} = 0$ and $\frac{\partial TEI(e_G, e_A, 0)}{\partial e_G} = 0$, we obtain $e_G^* = \frac{S - \frac{\theta}{\theta_o}}{2}$ and $e_A^* = \frac{S + \frac{\theta}{\theta_o}}{2}$. Given the non-negativity constraint in (4.5), it follows that $e_G^* > 0$ if and only if $S > \frac{\theta}{\theta_o}$.

(ii) Suppose $e_A^* = 0$. Solving $\frac{\partial TEI(e_G, 0, e_B)}{\partial e_B} = 0$ and $\frac{\partial TEI(e_G, 0, e_B)}{\partial e_G} = 0$, we obtain $e_G^* = \frac{S - S_2}{2}$ and $e_B^* = \frac{S + S_2}{2}$, where, S_2 is as given in Lemma 5(ii). Given the non-negativity constraint in (4.5), it follows that $e_G^* > 0$ if and only if $S > S_2$.

We next characterize conditions under which each of the above cases arises. Using the expressions of $e_A^*(e_G)$ and $e_B^*(e_G)$ from Lemma 2, and substituting $\alpha_{bA} = 0$ and $\alpha_{aB} = \alpha$, we have:

$$\frac{e_A^*(e_G)}{e_B^*(e_G)} = \left(\frac{p \cdot \theta(e_G) \cdot k}{p \cdot (1 - \theta(e_G)) \cdot \alpha \cdot k + (1 - p) \cdot \theta(e_G)} \right)^{\frac{1}{1-\beta}}.$$

Taking limit as β approaches 1, we get $\lim_{\beta \rightarrow 1} \frac{e_A^*(e_G)}{e_B^*(e_G)} = \infty$ if $p > \hat{p}(e_G)$ and $\lim_{\beta \rightarrow 1} \frac{e_A^*(e_G)}{e_B^*(e_G)} = 0$ if $p \leq \hat{p}(e_G)$, where $\hat{p}(e_G) \doteq \frac{1}{\left(k+1-\alpha \cdot k \cdot \left(\frac{1-\theta(e_G)}{\theta(e_G)}\right)\right)}$. This implies that $e_B^* = 0$ if $p > \hat{p}(e_G)$ and $e_A^* = 0$ if $p \leq \hat{p}(e_G)$.

Next, we show that $\frac{1}{k+1} \leq \hat{p}(e_G) < 1$ for any $e_G \geq 0$. Because $0 < \alpha < 1$, $k \geq 1$, and $\theta(e_G) \in [\frac{1}{2}, 1]$, we have $\alpha \cdot \left(\frac{1-\theta(e_G)}{\theta(e_G)}\right) < 1$, which implies that $\left(k+1-\alpha \cdot k \cdot \left(\frac{1-\theta(e_G)}{\theta(e_G)}\right)\right)^{-1} > \frac{1}{k+1}$ for all $0 \leq e_G < S$.

Considering the optimal advisory effort e_G^* , we next show that $\hat{p}(e_G^*)$ is a unique threshold and is increasing in α . Consider the following three cases based on the magnitude of e_G^* .

(a) If $e_G^* = 0$, we have $\hat{p}(0) = \left(k+1-\alpha \cdot k \cdot \left(\frac{1-\theta}{\theta}\right)\right)^{-1}$, which is increasing in α .

(b) If $e_G^* = \frac{S - \frac{\theta}{\theta_o}}{2}$, we have $\hat{p}\left(\frac{S - \frac{\theta}{\theta_o}}{2}\right) = \left(k+1-\alpha \cdot k \cdot \left(\frac{2-\theta-\theta_o S}{\theta+\theta_o S}\right)\right)^{-1}$, which is again increasing in α .

(c) If $e_G^* = \frac{S - S_2}{2}$, we have $\hat{p}\left(\frac{S - S_2}{2}\right) = \left(k+1-\alpha \cdot k \cdot \left(\frac{1-\theta\left(\frac{S - S_2}{2}\right)}{\theta\left(\frac{S - S_2}{2}\right)}\right)\right)^{-1}$. Substituting S_2

from Lemma 5(ii), we obtain $l(p, \alpha) \doteq p - \hat{p}\left(\frac{S-S_2}{2}\right)$ is a quadratic equation in p , which implies it has at most two roots. To establish the uniqueness of threshold, it is sufficient to show that, for a given $\alpha \in (0, 1)$, $l(p, \alpha)$ have a single crossing point for all $p \in (0, 1)$.

By in Corollary 1 (ii), we have that S_2 increases in p . Combining this result with the fact that $\theta(e_G)$ increases in e_G , we conclude that $\theta\left(\frac{S-S_2}{2}\right)$ decreases in p . This result implies that $\hat{p}\left(\frac{S-S_2}{2}\right)$ is increasing in p . In addition, because $0 < \alpha < 1$ and $\theta(e_G) \in \left[\frac{1}{2}, 1\right]$, we obtain

$$l(0, \alpha) = 0 - \frac{\theta(e_G(0))}{(k+1)\theta(e_G(0)) - \alpha.k.(1 - \theta(e_G(0)))} < 0, \quad (\text{D22})$$

$$l(1, \alpha) = 1 - \frac{\theta(e_G(1))}{(k+1)\theta(e_G(1)) - \alpha.k.(1 - \theta(e_G(1)))} > 0. \quad (\text{D23})$$

Combining the results in (D22)–(D23), we can conclude that, for any given $\alpha \in (0, 1)$, there exists a unique $p_{root} \in (0, 1)$, such that $l(p, \alpha) > 0$ if and only if $p > p_{root}$. Further, by Corollary 1(i) and the fact that $\theta(e_G)$ increases in e_G , we obtain $\frac{\partial}{\partial \alpha} \hat{p}\left(\frac{S-S_2}{2}\right) > 0$. This implies that the unique crossing point p_{root} increases in α . Combining the results, we obtain that $\bar{p}(\alpha) = \left(k+1 - \alpha.k.\left(\frac{1-\theta}{\underline{\theta}}\right)\right)^{-1}$ if $S \leq \frac{\theta}{\theta_o}$, $\bar{p}(\alpha) = \left(k+1 - \alpha.k.\left(\frac{2-\theta-\theta_o S}{\underline{\theta}+\theta_o S}\right)\right)^{-1}$ if $\frac{\theta}{\theta_o} < S \leq S_2$, and $\bar{p}(\alpha) = p_{root}(\alpha)$ otherwise. In addition, as shown above in all three cases, $\bar{p}(\alpha)$ is increasing in α . Finally, the proof implies that $\hat{S}_G(\alpha) = \frac{\theta}{\theta_o}$ if $p > \bar{p}(\alpha)$, and $\hat{S}_G(\alpha) = S_2$ if $p \leq \bar{p}(\alpha)$; thus, when $p > \bar{p}(\alpha)$, $\frac{\partial}{\partial \alpha} \hat{S}_G(\alpha) = 0$, and when $p \leq \bar{p}(\alpha)$, $\frac{\partial}{\partial \alpha} \hat{S}_G(\alpha) > 0$ as shown in Corollary 1 (i). \square

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